Palestine Polytechnic University

College of Engineering

Title

Design of Multiband Microstrip Antenna for GSM, Wifi, and Wimax Application

By

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Dedication

This work is lovingly dedicated to

Our Parents

For their endless love, support and encouragement.

Contents

Preface

This documentation contains six chapters, and these chapters are arranged in the order described below.

Chapter1; in this chapter an overview of the microstrip antennas is presented showing its importance for the researchers and communication applications, then a brief presentation of the various configuration of the microstrip patch antennas is given. The objectives of this study is discussed then the methodology of the research we proposed to follow to get the desired results is presented. Afterward a very brief and short discussion of the main advantages and disadvantage of the microstrip antennas is given.

Chapter 2; in this chapter a general description of the theory of the microstrip antennas is shown. Several feeding techniques used in microstrip antennas, such as, coaxial line and microstrip feeding is discussed. Then a general description of the methods of analysis used in microstrip antennas, such as, transmission line model and cavity model is given.

Chapter 3; this chapter describe in general the history of microstrip antennas and present the main and key developments in that field. Then the classification of the antennas, such as, microstrip patch antenna and microstrip patch antenna is discussed and presented. The use of microstip antennas in the different applications, such as, RFID, radar, and mobile communications is discussed.

Chapter 4; chapter 4 discusses the main parameters used to characterize the antenna. Directivity and gain is presented and the difference between the two is discussed. Radiation pattern is also discussed and the parameters used to compare radiation patterns are presented. Then return loss, bandwidth, and antenna impedance is given.

Chapter 5; this chapter discusses the procedure we followed in our research and discusses the different parameters affecting the performance of the antenna. The main results, such as radiation patterns, gain, VSWR, and others is given and discussed, and the final design is show and discussed.

Chapter 6; the simulated results of the project is discussed.

Chapter 7; the measured and the experimental results are discussed

Acknowledgement

We would like to sincerely thank our supervisor Dr. Osama Ata, for his guidance and support throughout this study. Without his unlimited patience, passionate support, and invaluable feedback, the study would not have been successfully conducted.

We would like to thank our parents for providing us with unfailing support and continuous encouragement throughout our years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without their help.

We would like to thank our teachers and friends at Palestine Polytechnic University.

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List of Abbreviations

WLAN	Wireless Local Area Network
FR-4	Flame Retardant
GSM	Global System for Mobile Communication
WiMAX	Worldwide Interoperability for Microwave Access
CST	Computer Simulation Technology
DGS	Defected Ground Structure
MIMO	Multiple Input Multiple Output
RFID	Radio Frequency Identifications
GPS	Global Positioning System
MICs	Microwave Integrated Circuits
RF	Radio Frequency
CPW	Coplanar Waveguide
EM	Electromagnetic
FDTD	Finite Difference Time Domain
FEM	Finite Element Method
PBG	Photonic Bandgap
IEEE	The Institute of Electrical and Electronics Engineers
VLF	Very Low Frequency
LF	Low Frequency
HF	High Frequency
VHF	Very High Frequency
MPA	Microstrip Patch Antenna
MTA	Microstrip Traveling Wave Antenna
TEM	Transverse Electromagnetic
UHF	Ultra High Frequency
HPBW	Half-power beamwidth

Abstract

In recent years, there has been a big and rapid development in the communication and network industry. To be more specific, there has been a big and tremendous growth in the technologies of wireless local area networks (WLAN), the worldwide interoperability for microwave access (WiMAX) and GSM communications. For this reason, there is an increasing demand for miniature, low profile, low-cost, and easy to fabricate antennas with a broad range of frequency bands. Having almost all these features, microstrip antennas attracted the interest of researchers to delve into the study, investigation, and design of this type of antennas.

In this project, a simple structure, low-cost, and low-profile U-slotted microstrip patch antenna has been designed, fabricated, measured and implemented to operate at three desired frequencies, that is, 1.8GHz (GSM), 2.44GHz (WLAN), 3.5GHz (WiMAX).

In the design process, the effects of several parameters on the performance of the antenna have been studied, utilizing an international standard antenna software called CST Studio Suite. The length and width of the patch, the length, widths, and the gaps of the U-shaped slots were all implemented in the design simulation. The antenna was first measured as far as return loss, using a network analyzer, provided by the national operator; Al-Wataniya Mobile. The radiation patterns were measured in-house, utilizing an antenna measurement system. Then the fabricated antenna was tested in a simple WLAN network, where performance against various distances is verified and measured.

ملخص المشروع

نظرا للتطور السريع و الكبير في مجال الاتصالات اللاسلكية و الشبكات و خاصة الشبكات اللاسلكية ، فإن هناك حاجة ماسة الى هوائيات ذات حجم صغير و تكلفة بسيطة و كذلك سهلة التصنيع لتستخدم في هذه المجالات.

في هذا المشروع ، قمنا بتصميم وتصنيع واختبار الهوائي في احد اكثر التطبيقات اهمية وهو WiFi. تمت عملية القياسات المتعلقة في المشروع في شركة الوطنية للاتصالات وذلك لتوفر الادوات اللازمة لإجراء هذه القياسات. يتميز الهوائيبقدرته على العمل على ثلاثة مجالات ترددية. هذه المجالات هي مجال 2.4GHz و المستخدم للشبكات اللاسلكية (WLAN) و مجال 1.8GHz و المستخدم في شبكات الهواتف الخلوية(GSM) و مجال 3.5GHz (WiMAX).

Chapter 1

Introduction and Background

1.1 Overview.

1.2 Microstrip Antenna Configurations.

1.3 Objectives of the Study.

1.4 Methodology of the Study.

1.5 Applications of Microstrip Antenna.

1.6 Advantages and Disadvantages of Patch Antenna.

1.7 Background of the Study.

1.8 Time Schedule.

CHAPTER ONE

Introduction

1.1Overview

Current revolution in Telecommunication and Electronic field has a lot of challenges including design and development of a small and high efficiency antenna. There are different Antennas are used in telecommunication system these days, one of them is called microstrip patch Antenna, also just called Patch Antenna[1]. Since current product have a small size such as personal communication service such as mobile phone and WLAN, this lead to challenge in antenna design, so modern antenna must meet the requirement of multiband. The antenna must also be with a small size to be placed inside minimized wireless communication system. In its basic form, a microstrip Antenna consist of a three Layer:

a- Patch.

b- Substrate.

c- Ground plane.

The Patch and the ground plane is generally made of conducting material such as Copper or Gold. The Patch can take any possible shape such as C, L, E, and U etc. The Substrate layer is located between Patch and the Ground Plane, and it's mainly made of a dielectric material such as FR-4, as shown in **Figure 1.1**.

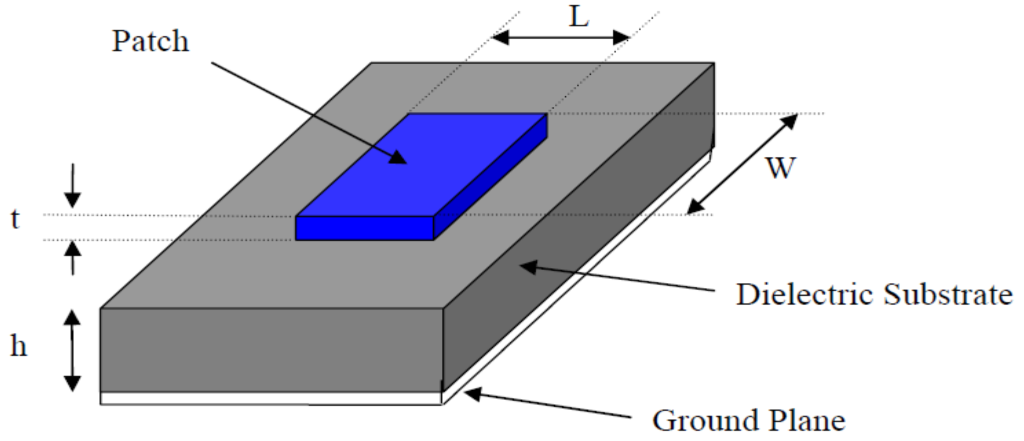


Figure 1.1: Structure of a microstrip Patch Antenna.

Microstrip Patch Antenna radiate primarily because of the fringing fields between the Patch edge and the ground plane. For good Antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provide better efficiency, large bandwidth and better radiation. Microstrip Antenna sometimes known as Printed Antenna, this because the fabrication process of microstrip Antenna occur on the printed board. Many type of microstrip Antenna was developed which are different in the basic structure.

1.2 Microstrip Antenna Configurations

During the intensive research on microstrip Antenna until now, there are a lot of shapes have been designed in order to enhance performance of microstrip Antenna. A common shape such as rectangular, circular and triangle, etc. as shown in **Figure 1.2**.

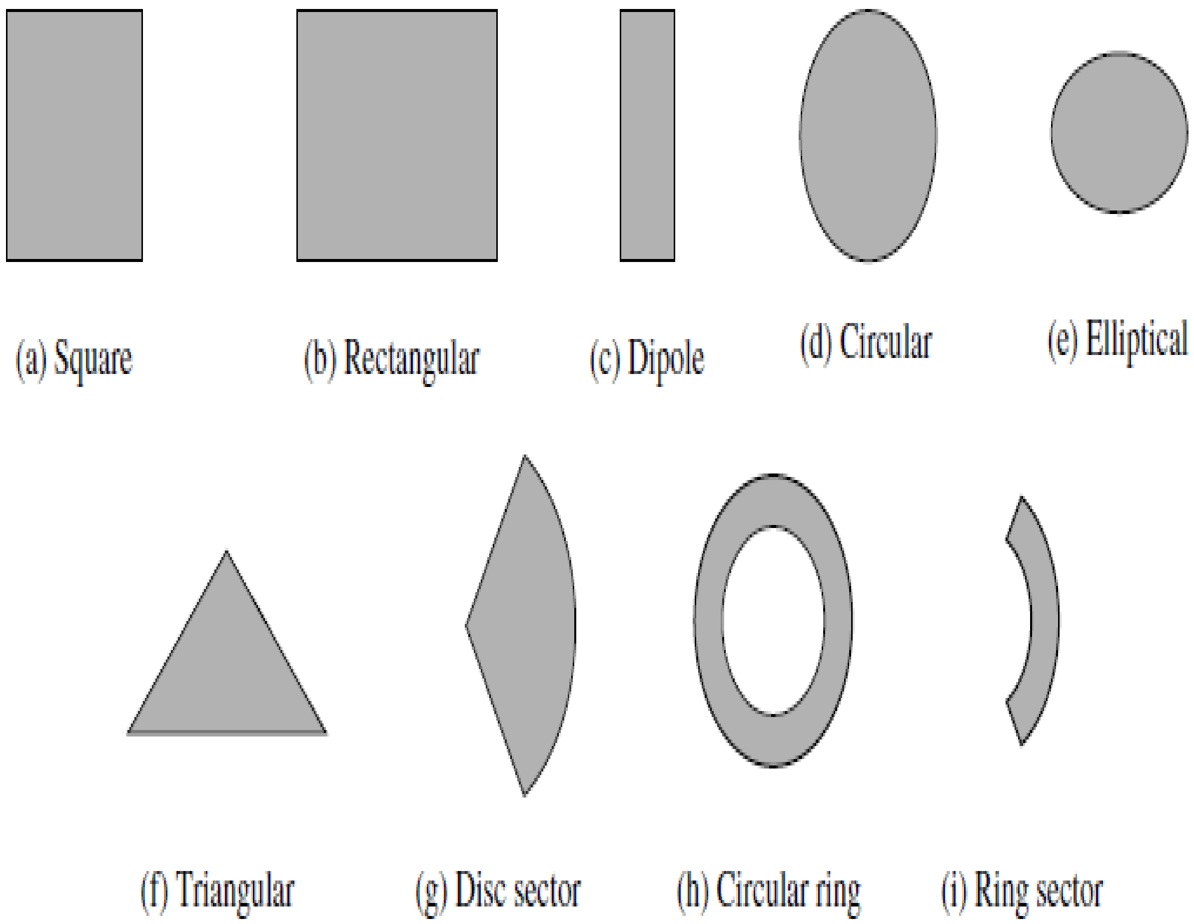


Figure 1.2: Shapes of microstrip Antenna.

1.3 Objective of the Study

Due to the fact that there is a great and increasing demand on low cost, low profile, and broadband antennas to operate at different frequency regions to cover different applications, researchers and scientists have delved into the study of behavior and performance of microstrip antennas. So this study is intended to be a contribution in that realm.

There are three main objectives for this study:

a. To design a new dual wideband microstrip antenna using U–slot techniques for applications in GSM, WLAN and WiMAX.

b. To improve bandwidth and return loss of the proposed antenna.

c. To test this Antenna on some Applications such as WLAN.

1.4 Methodology of the study

To achieve the objectives of this study, we intend to use the Computer Simulation Technology (CST). Thiswill help to design a new shape of microstrip antenna. the main idea is to use U-slot technique in order to achieve theobjective of this project. Recently, extensive research in microstrip antenna design using U- slot technique.

The developed methodology for designing microstrip Patch Antenna is illustrated in the flow chart depicted in **Figure 1.3**.

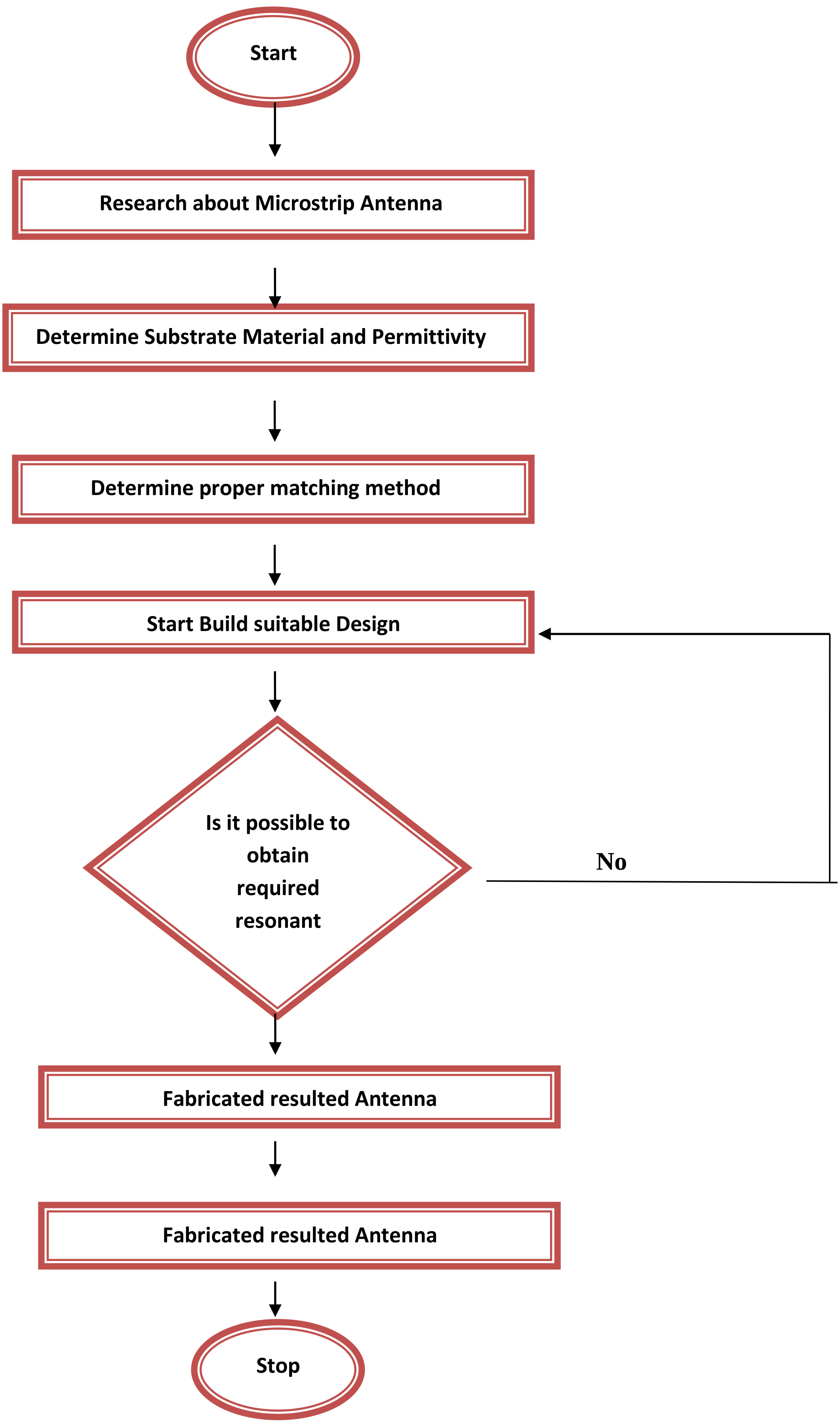


Figure1.3: Flow chart of the project.

1.5 Application of Microstrip Antenna

Since current product has a small size such as personal communication service such as mobile phone and WLAN, this lead to challenge in antenna design, so modern antenna must meet the requirement of multiband. The antenna must also have a small size to be placed inside minimized wireless communication system.Microstrip patch antenna are used all around the world in several applications for government, civilian and commercial applications such as Global Positioning System(GPS), Multi-input Multi-output(MIMO), Radio Frequency Identification(RFID), WLAN and WiMAX etc. WLAN and WiMAX standards specify many bandwidth and many operating frequencies around the world; therefore to satisfy these applications a multi band antennas are required for the future communication terminal[1].

1.6 Advantages and Disadvantages of Patch Antennas

Patch antenna for dual and multiband become an interesting topic these days because of its advantages such as**:**

- Light weight and low volume.
- Low fabrication cost, hence can be manufactured in large quantities.
- Can be easily integrated with Microwave Integrated Circuits(MICs).
- Capable of dual and triple frequency operation.

Microstrip Patch Antennas suffer from a number of disadvantages such as:

- Narrow bandwidth.
- Low efficiency.
- Low Gain.
- Low power handling capacity.

1.7 Literature Review

In recent years, with rapid development in communications fields, this rapid development creates the need of multi-band or broadband antennas with small size and high efficiency. Since microstrip antenna have the advantages of small size and low weight so microstrip antenna is one of the most popular antenna these days. Microstrip patch antenna was basically introduced in 1953. It was proposed by Deschamps that microstrip feed lines can be used to feed an array of printed antenna element [2].However, 20 years passed before practical antennas were fabricated. Development during the 1970s was accelerated by the availability of good substrate with low loss tangent and attractive thermal and mechanical properties improved photo lithographic techniques and better theoretical model.Several shapes of rectangular and circular microstrip antenna have been published [3]. In recent years the most popular technique used to design microstrip antenna is using U- slot technique. In [4] a double U-slots microstrip patch antenna for WiMAX application is presented, in this paper two U-slot is obtained in the patch in order to obtain tri-band operation.

Extensive research and development of microstrip patch antenna was done. In [5]a design of Microstrip patch antenna with using Elliptical patch and double U-slot which obtained in the patch. In [6] a novel compact single and dual band-Notched printed monopole antenna with a pair of L-shaped slot has been presented. Frequency band of proposed antenna is in between 3 to 14 GHz and fractional bandwidth 130%.

1.8 Time Schedule

Table1.1: duration of the project (first semester)

Total time available	4 months (from 4 September to 11 December 2016)													
Number of Weeks / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Choosing of the subject														
Related books														
Reading/Journal review														
Writing Proposal														
Simulation using (CST)														
Analysis &evaluation														
Supervisor review														
Writing up														
Final correction														
Printing														

Table1.2: duration of the project (second semester)

Total time available	4 months (from 1 February to 11 May 2017)													
Number of weeks / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Simulation														
Searching for materials														
Fabrication														
Measurements														
Writing up														
Final correction														
Printing														

Chapter 2

Microstrip Antenna Theory

2.1 Basic Principle of Operation

2.2 Feeding Techniques

2.3 Rectangular Patch

2.4 Circular Patch

Chapter Two

Microstrip Antenna Theory

2.1 Basic Principle of Operation

Microstrip Patch Antenna in its basic form: a flat plate over a ground plane, as shown in **Figure 2.1**. This Antenna is built on a printed circuit board. A microstrip patch antenna is a radiating patch on one side of a dielectric substrate, whichhas a ground plane on the underside.

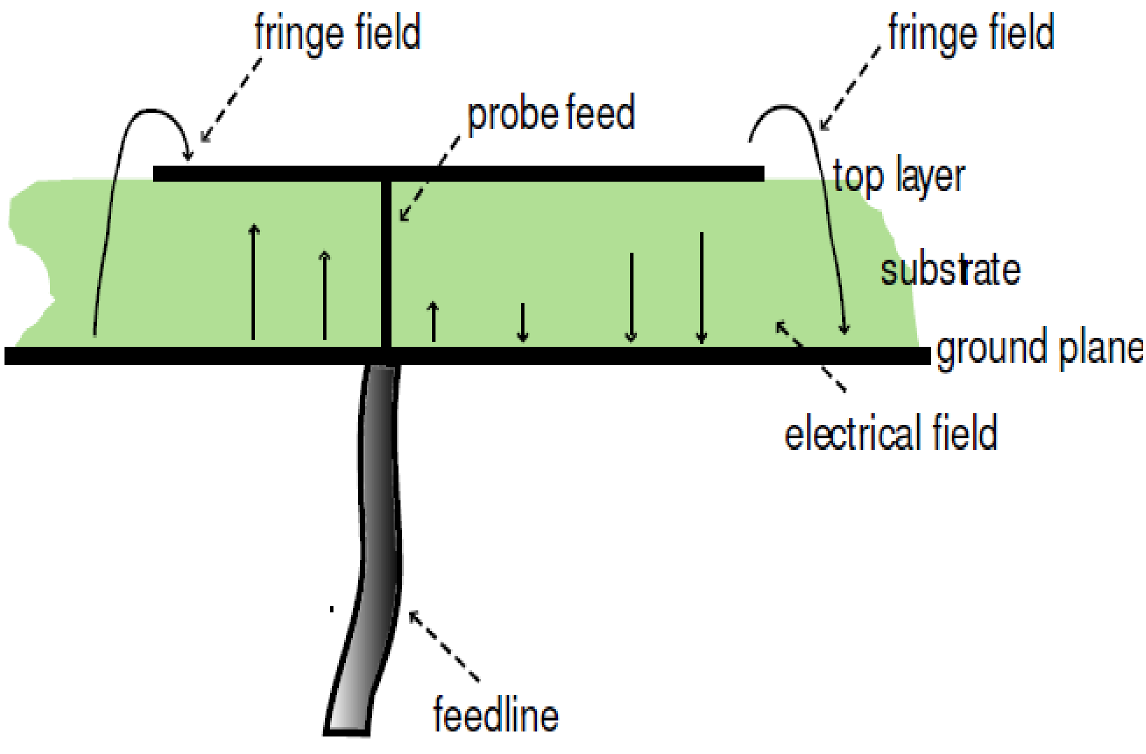


Figure 2.1: Cross section of a patch antenna in its basic form.

As shown in **Figure 2.1**, the center conductor of a coaxial line serves as the feed probeto couple electromagnetic energy in and/or out of the patch.The EM waves fringe off the top patch into the substrate, reflecting off the ground plane and radiates out into the air. Radiation occurs mostly due to the fringing field between the patch and ground, as shown in **Figure 2.2**. A thicker substrate leads to alonger feed probe, a larger feed probe inductance and a degradation of impedancematching. This can be compensated by using a different feed type and we’ll look ataltemative feed methods further down[4].

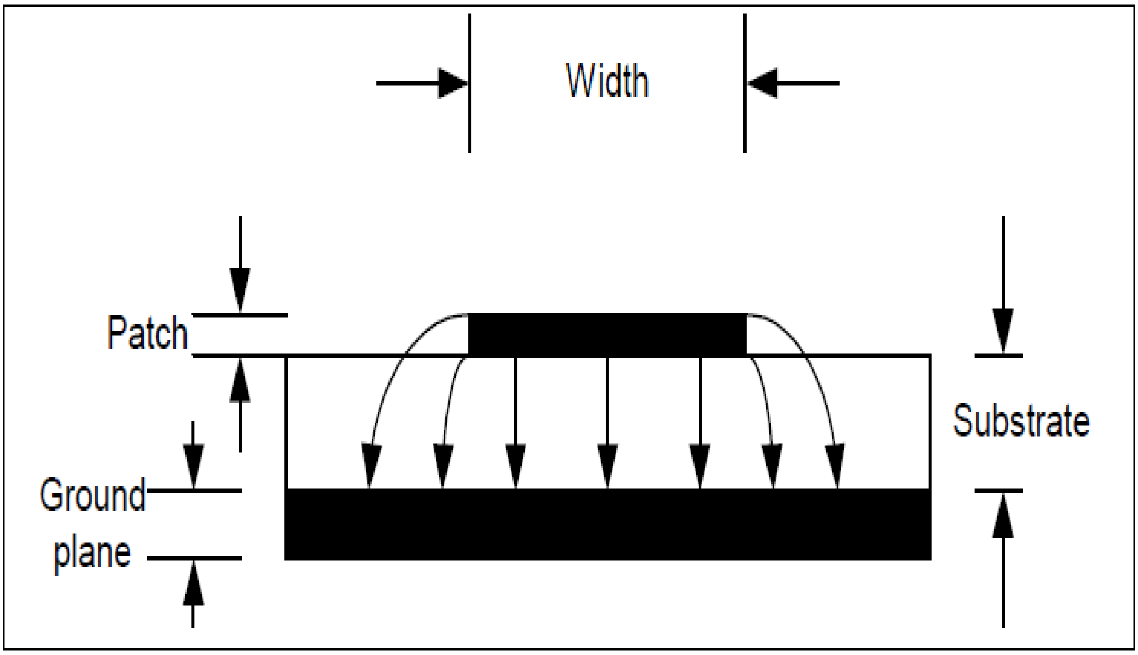


Figure2.2: Operations of a microstrip Patch Antenna.

The radiation efficiency of the patch antenna depends largely on the permittivity ofthe dielectric. Ideally, a thick dielectric, low permittivity and low insertion loss is preferred forbroadband purposes and increased efficiency.

2.2 Feeding Techniques

In the theory of microstrip antennas, there are several techniques and methods to feed and energize the microstrip antennas. Amongst those methods and techniques, there is the microstrip line, coaxial cable, coplanar waveguide, and many others. In this section we are going to discuss those different modes and methods[7].

Microstrip Patch Antenna can be fed by some method. These methods can be classified into two categories:

a. Containing Method.
b. Non- Containing Method.

In the Containing method, the patch is directly fed with RF power using the contacting element such as microstrip line or coaxial line. The most commonly used contacting fed methods are microstrip Feed and Co-Axial Feed. In the Non-Containing method, the patch is not directly fed with the RF power but instead power is transferred to the path from the feed line through electromagnetic coupling. The most commonly used no contacting feed methods are Aperture Coupled feed and Proximity Coupled Feed.

2.2.1 Coaxial Line Feeding

One of the common feeding techniques used in the design of microstrip antennas is the coaxial line feeding or known as prop coupling. In this feeding structure, the inner conductor is connected to the patch of the antenna whereby the outer conductor is connected to the ground plane of the antenna as shown in **Figure2.3** and **Figure 2.4**. Impedance matching between the coaxial line and the patch can be reached by adjusting the location of the feeding point. However, this technique has its drawbacks. As a result of using multiple soldering points, a spurious surface waves is generated, the input impedance is affected, and other effects. Those effects will have an impact on the bandwidth of the antenna[8].

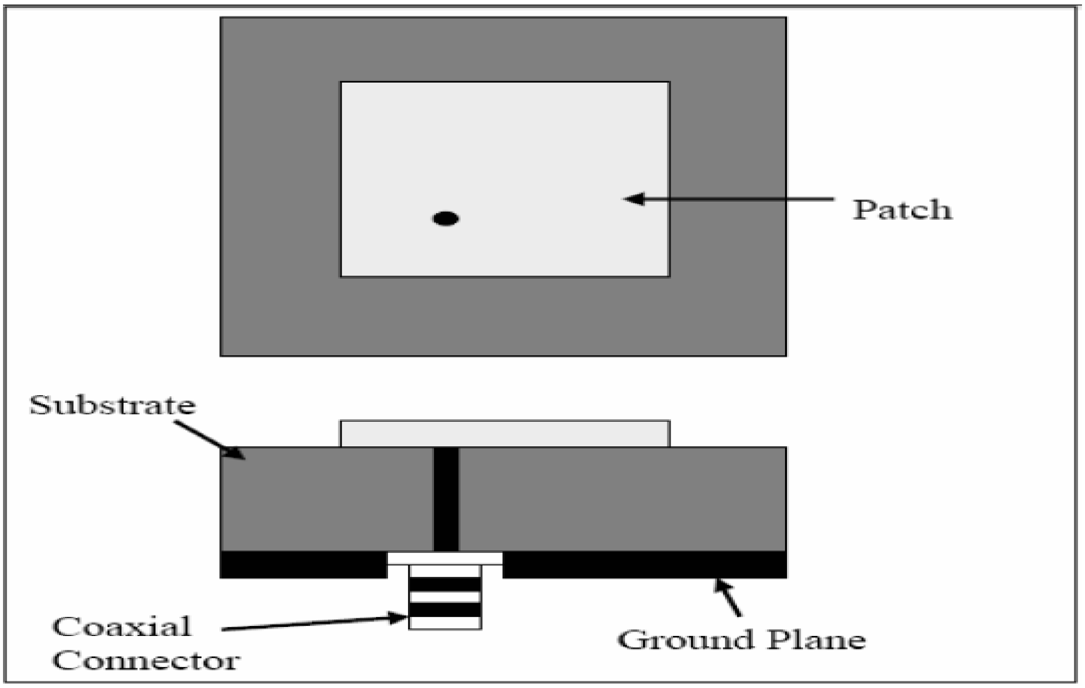


Figure 2.3: Coaxial feed line structure.

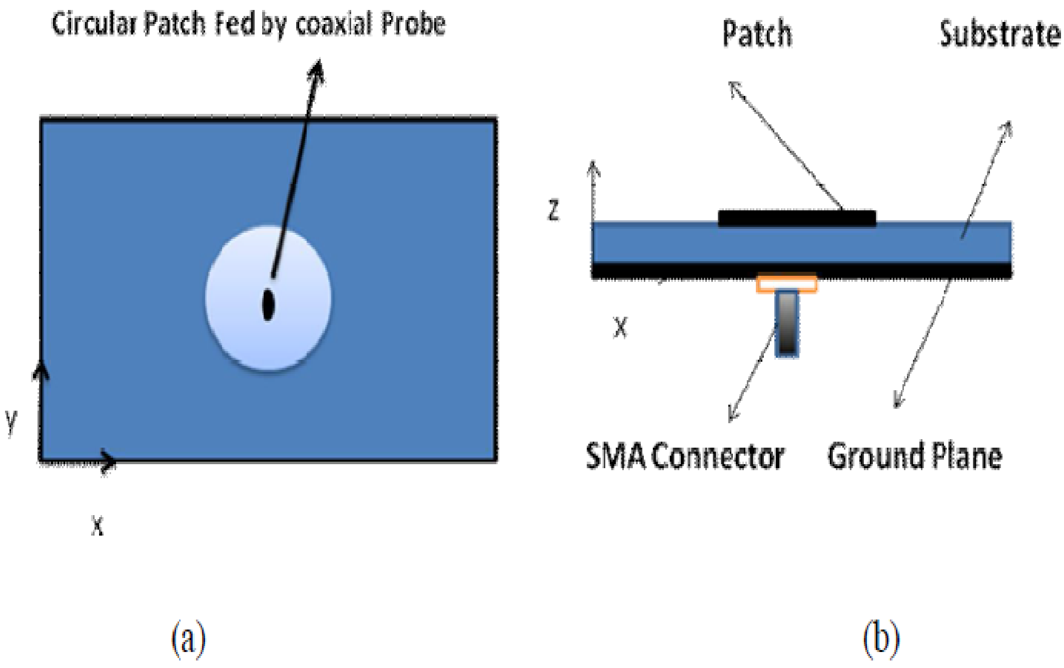


Figure 2.4: Structure of probe coupling method a- top view, b- side view.

2.2.2 Microstrip Line Feed

Another feeding technique that can be applied to overcome those drawbacks off the coaxial line feeding is the usage of microstrip line feeding as shown in **Figure 2.5** and **Figure 2.6**. The feeding strip can be fed by a transmission line or coaxial line. In this feeding method, a good matching between the strip line and the patch must be achieved to get better band width. There are several methods that can be used to do that such as notching the edge of the patch, quarter-wavelength transformer, or, and not limited to, matching stubs [9].

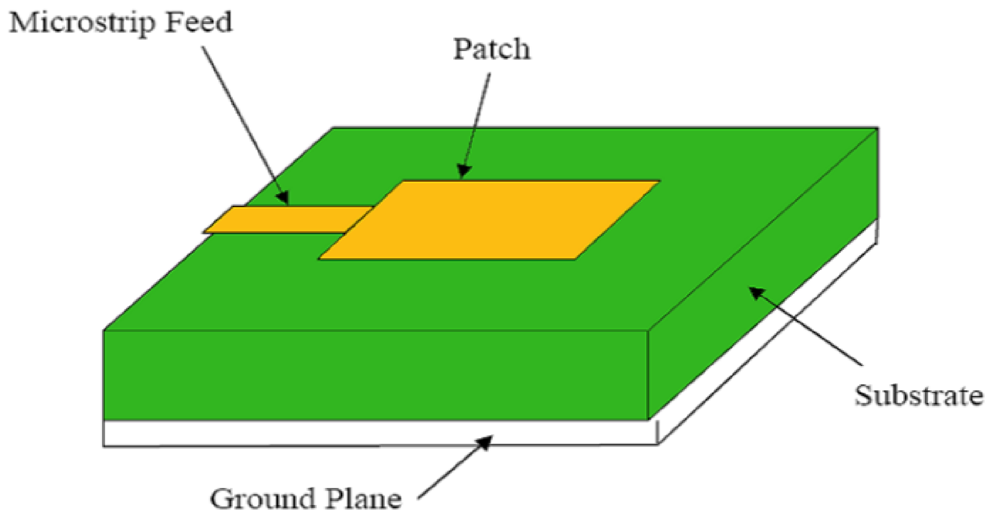


Figure 2.5: Structure of microstrip line feed.

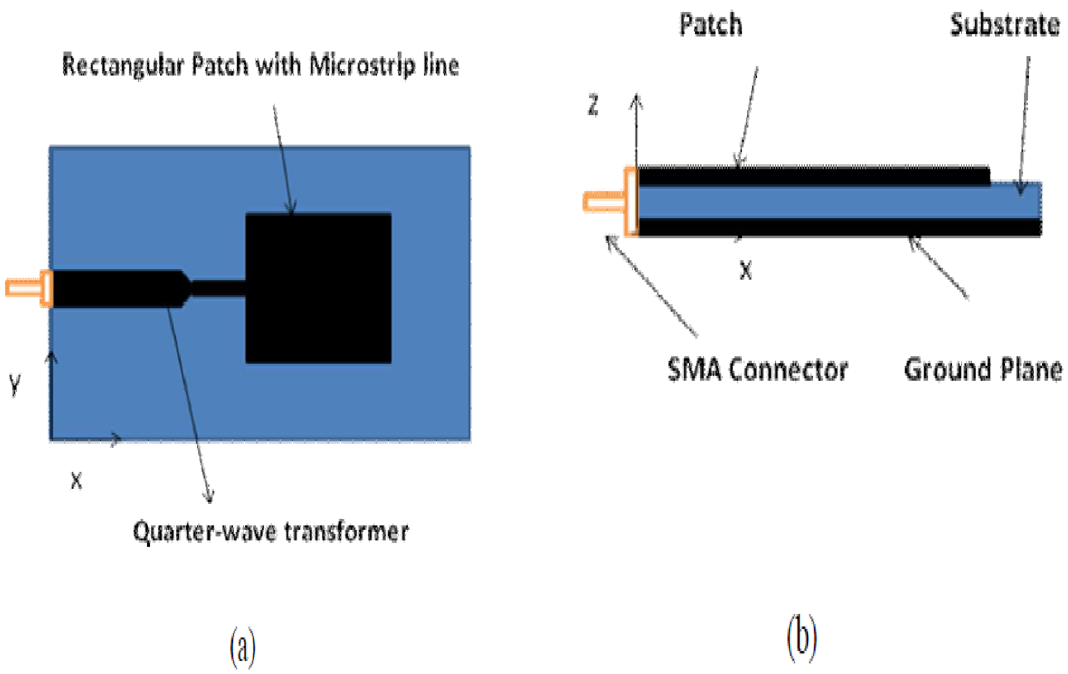


Figure2.6: Microstrip line feed for rectangular patch antenna a. Top view   b. Side view.

2.2.3 Aperture Coupled Feed Method

Another method of feeding microstrip antennas is called the aperture feed. In this technique, the transmission line is shielded from the antenna by a conducting plane with a whole(aperture) to transmit energy to the antenna, as shown in **Figure2.7**. The upper substrate can be made with a lower permittivity to produce loosely bound fringing fields, yielding better radiation. The lower substrate can be independently made with a high value of permittivity for tightly coupled fields that don't produce spurious radiation. The disadvantage of this method is increased difficulty in fabrication[10].

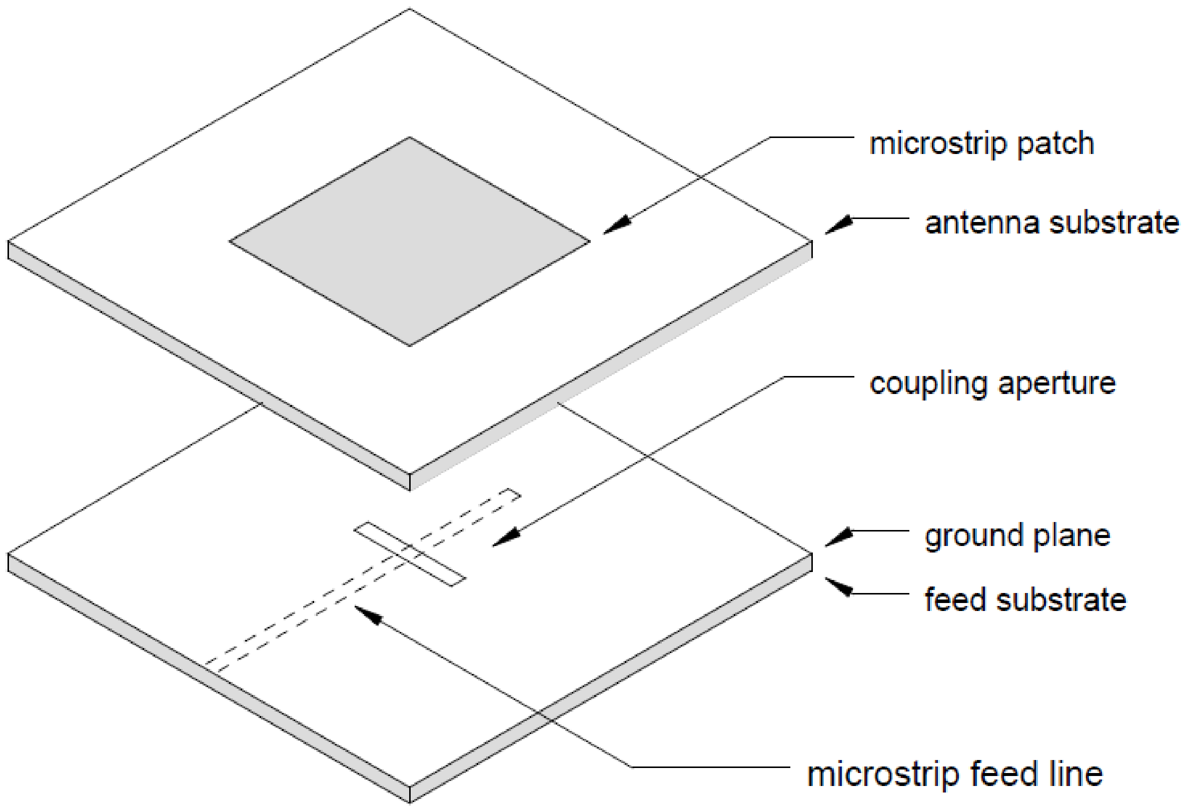


Figure 2.7: Structure of the basic aperture coupled microstrip antenna.

2.2.4 Coplanar Waveguide

Coplanar waveguide can also be used as feeding method to energize the microstrip antenna. As shown in the **Figure 2.8** and **Figure 2.9**. Coplanar waveguide (CPW) is formed from a conductor separated from a pair of ground planes, all on the same plane, atop a dielectric medium. In the ideal case, the thickness of the dielectric is infinite; in practice, it is thick enough so that EM fields die out before they get out of the substrate. The advantages of coplanar waveguide are that active devices can be mounted on top of the circuit, like on microstrip. However, the main reason that CPW is not used is that there is a general lack of understanding of how to employ it within the microwave design community[11].

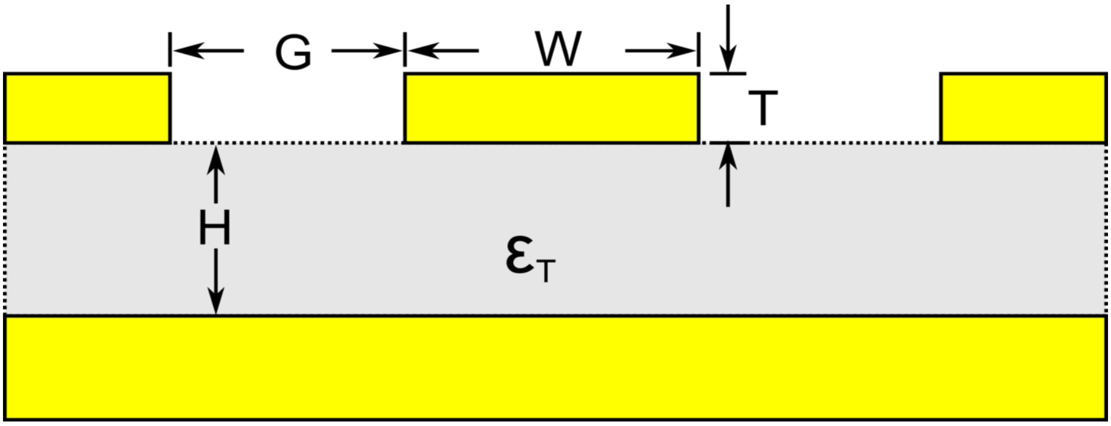


Figure 2.8: Structure of Coplanar Waveguide(CPW).

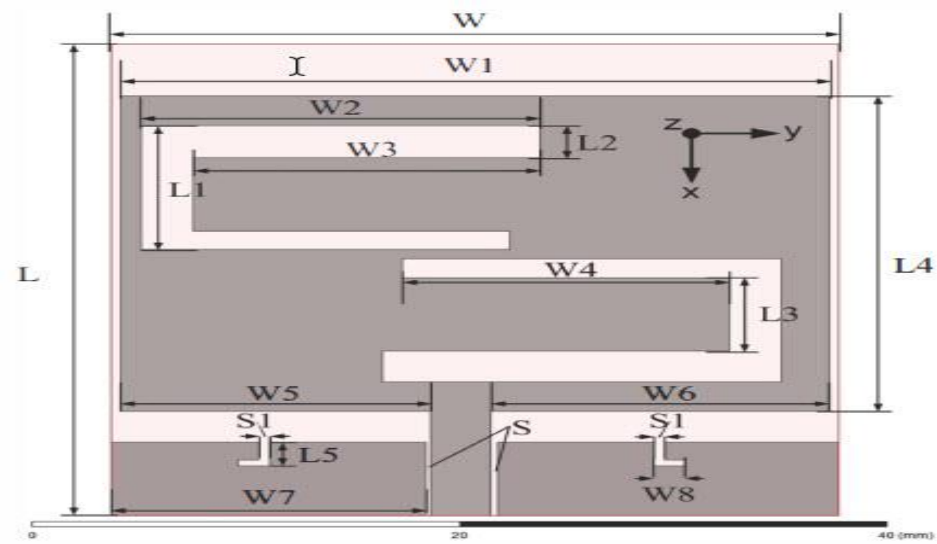


Figure 2.9: Coplanar Waveguide used in a U-shaped Slot Antenna.

2.3 Rectangular Patch.

Rectangular patch antenna is the most popular antenna due to its modeling and fabrication easiness. In this section we are going to analyze the rectangular patch antenna using both transmission line model and cavity model.

2.3.1 Transmission Line Model

It is known that transmission line model for analysis is the simplest and the easiest amongst the others. However, it lacks for accuracy and versatility compared to the others. In this subsection we are going to examine different parameters and see its effects on the performance of the patch antenna[12].

One of important factors that must take great consideration is the fringing fields. In case of the patch antenna, as a result of the dimensions of the patch being finite, the fields on the edges of the patch suffer from fringing as shown in **Figure 2.10**. These fringing is a function of the dimensions of the patch and the height of the substrate.

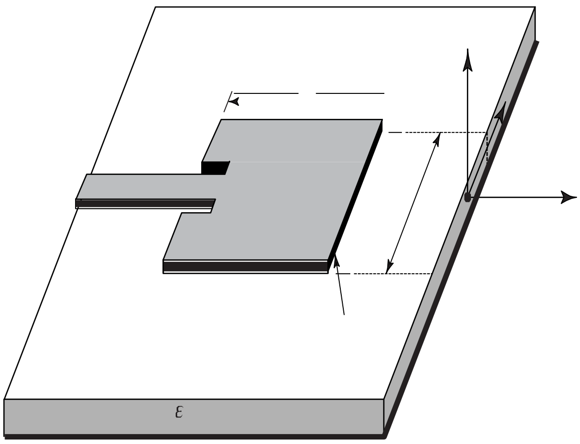


Figure 2.10: Fringing field of MPA.

As W/h >> 1, where W is the width of the patch and h is the thickness of the substrate, and ε>>1, most of the electric field lines resides into the substrate. In this case, fringing fields make the antenna looks electrically wider than physically it is[12]. For some of the electric fields lines concentrate in the substrate and some exit to the air an effective dielectric constant is introduced. The effective dielectric constant is given by equation 2.1for W/h > 1[12].

$$\varepsilon_{eff} = \frac{\varepsilon_{eff}+1}{2} + \frac{\varepsilon_{eff}-1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$ Equation (2.1)

As a result of the fringing fields, the dimensions of the patch Looks different from its physical dimensions. Along its length the patch looks longer by ΔL and it is given by[12]:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)}$$ Equation (2.2)

As the length of the patch is extended by ΔL, its effective length now is given by[12]:

$$L_{eff} = \Delta L + 2L$$ Equation (2.3)

In the case of the dominant mode TM_{010}, the resonant frequency is a function of the length of the patch and it is given by[12]:

$$f = \frac{v}{2L\sqrt{\varepsilon_r}}$$ Equation (2.4)

2.3.2 Cavity Model

The field configurations within the substrate can be found using vector potential approach. The volume below the patch can be modeled as a cavity loaded with a dielectric with dielectric constant of ε as shown in **Figure 2.11**.

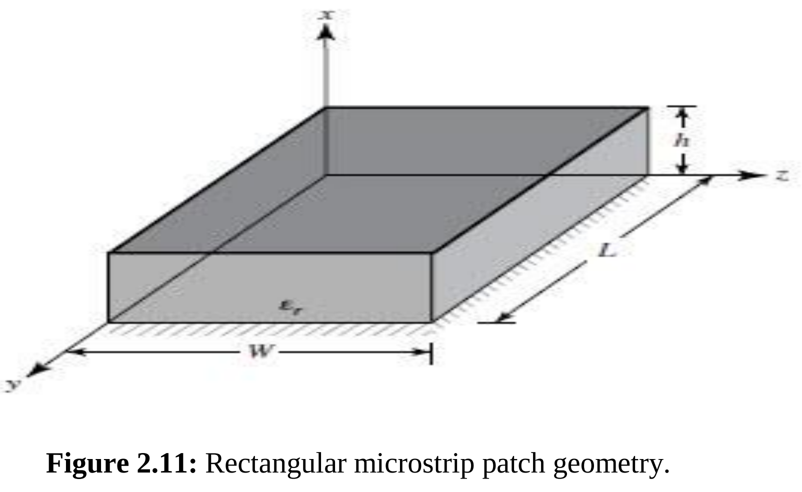


Figure 2.11: Rectangular microstrip patch geometry.

The resonant frequencies of the cavity is given by[12]:

$$f = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{h}\right)^2 + \left(\frac{n\pi}{L}\right)^2 + \left(\frac{p\pi}{W}\right)^2} \qquad \text{Equation (2.5)}$$

For the dominant mode TM_{010}, the resonant frequency will reduce to[12]:

$$f = \frac{v}{2L\sqrt{\varepsilon_r}} \qquad \text{Equation (2.6)}$$

2.4 Circular Patch

Circular patch antenna is the second most common microstrip antenna. In this section, we are going to discuss several aspects and issues related to this kind of antennas.

As in the case of rectangular patch antenna, the patch, the ground, and the substrate between the two will be treated as a circular cavity as shown in **Figure 2.12**.

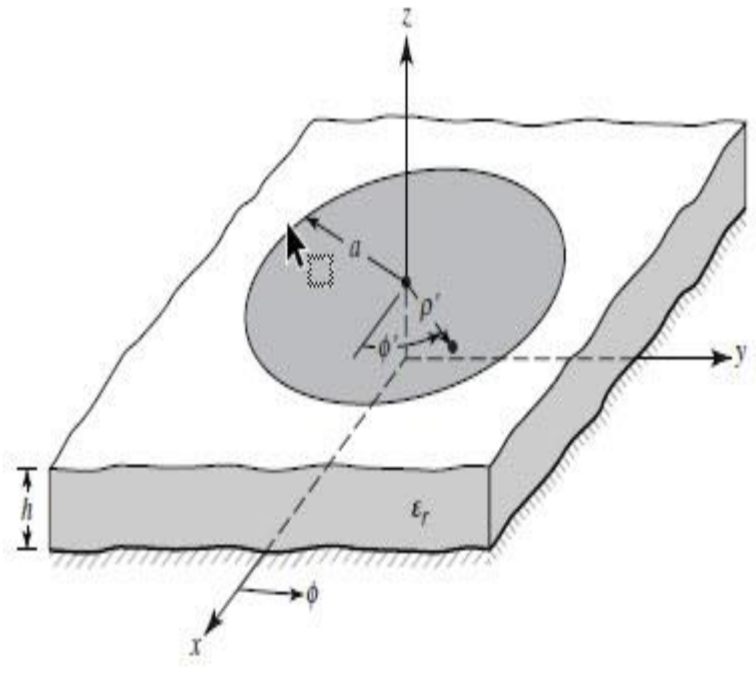


Figure 2.12: Geometry of circular microstrip patch antenna.

For a microstrip antenna whose substrate thickness is small, that is, h << λ, the supported modes are TM^Z_{mnp}, where Z is perpendicular to the patch. Since the height of the substrate is small, the fields along the z-axis is constant and p = 0. As a result, the frequencies of the cavity can be written as[12]:

$$f = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\left(\frac{X'_{mn}}{a}\right) \quad \text{Equation (2.7)}$$

For the dominant mode TM_{110}, the resonant frequency is given by[12]:

$$f = \frac{1.8412}{2\pi\sqrt{\mu\varepsilon}} \quad \text{Equation (2.8)}$$

Taking the fringing fields in the consideration, a correction is introduced by the effective radius to replace the actual radius of the patch is given by[12]:

$$a_e = a\left\{1 + \frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\} \quad \text{Equation (2.9)}$$

Chapter 3

Background

3.1 History

3.2 General Classifications of Antenna

3.3 Classification of Microstrip Antenna

3.4 Application of Microstrip Antenna

Chapter Three

Background

3.1 History

Often described as one of the most exciting developments in antenna and electromagnetic history, the microstrip patch antenna has matured into probably the most versatile solutions to many systems requiring a radiating element. Microstrip patch antennas fall into the category of printed antennas: radiating elements that utilize printed circuit manufacturing processes to develop the feed and radiating structure. Of all the printed antennas, including dipoles, slots and tapered slots, microstrip patches are by far the most popular and adaptable. This is because of all their salient features: including ease of integration, good radiation control and low cost of production[13].

Over many years of research and development, some of the more advancedforms of microstrip patches have responses that are more aligned tocharacteristics of traveling wave antennas: of course at the expense of thesimplicity of the antenna.

Research and development on the topic of microstrip patch antennashas been undertaken for the past 30 or so years with contributions from manycompanies, government organizations and universities throughout the world.Below is a summary of probably the more pertinent developmentsin the history of microstrip patch technology:

1970's

In the mid-1970s probably saw the first real contributions to the areaof microstrip patch technology. Although there were some patents on thissubject filed many years beforehand, it was really in this timeframe when thefirst significant advancements were made. In particular, two styles ofexciting/feeding a microstrip patch antenna were developed: the edge-fedpatch and the probe fed patch. These two types of excitation methods are really the 'fathers' of all patches, highlighting many of the inherentadvantages of microstrip patch antennas.

1980's

Research and development into microstrip patch technologycontinued into the 1980s, with major contributions once again coming fromthe defense industries, whether in the form of direct R&D or in grants.Probably the more significant advancements came as a result of trying toimprove on the inherent issues of the microstrip patch: the most well documented being the narrow impedance bandwidth of the patch antenna.Both edge and probe fed style patches had impedance bandwidths less a fewpercent and this value really depended on the material used as the groundedsubstrate. Contrary to this the radiation bandwidth (where the gain drops by 3dB) of these microstrip patches was quite broad in access of 30 %. This is afundamental reason as to why the majority of research on the microstrip patchantenna has been conducted on ways of improving the impedance nature ofthe antenna, rather than its radiation limits.

As a direct result in improved computer capabilities, in terms of speedand processing ability, more sophisticated software tools were able to bedeveloped. Integral Equation techniques were introduced in the 1980s [14, 15],with respect to microstrip patches and these methods allowed more accuratepredictions of the antenna, in terms of its impedance response. Computationalspeeds were not fast enough to allow for using these new numerical methodsto be used for design algorithms and also the tools became cumbersome whennon-conical shapes were considered. Infinite array codes were also developedto predict the performance of large scanned arrays of microstrip patches andscan blindness phenomenon (where power is trapped within the array and notradiated) were studied [16, 17].

1990's

The 1990s saw the development of microstrip patch technology into commercial systems. One primary application was for mobile communication base station terminals. Several versions of the microstrip patch were developed depending on the company, all with different capabilities and performance specifications. Most were developed using sheet metal manufacturing techniques, so the purest may argue that these antennas were not true printed antennas. However, despite this, it had become apparent that the commercial applications were now truly driving the design. In some respects, the years of hype that had surrounded the microstrip patch were now forcing patch antenna designers to 'deliver the goods'.

Some excellent development really dominated the microstrip patch landscape in the 1990s and associated with this, which is typically the case, some very good research resulted. Sophisticated analytical tools were now available as software packages and there was completion between software houses. The integral equation technique based codes were fast enough that designers could use them to yield minimal design iterations. Also Finite Difference Time Domain (FDTD) and Finite Element Method (FEM) were introduced to analyzing microstrip patch problems with the added feature of being able to analyze the surrounding environment. At this stage though these tools were too slow to use as a true designer software package.

2000's

By the tum of the century microstrip patches were pretty well being used in most 'free-space' communication systems or at least one of the first considered for them! (Probably with the exemption of multi-octave radar and earth stations) Further enhancements in bandwidth have been achieved (some using variations of the excitation method). More and more examples of integration are surfacing, including for spatial power combiner application, as well as other high gain solutions that had minimal feed network loss. Utilizing Photonic Bandgap (PBG) structures to enhance the efficiency and improve the overall radiation performance of the patch antenna have been explored. Attempts have been made to use optimization procedures (for example, genetic algorithms) to ensure the 'optimum' performance could be achieved.

3.2 General Classifications of Antenna

Antennas are an important part in any telecommunications system. The IEEE Standard Definitions of Antenna is "An antenna is any device that converts electronic Signals to electromagnetic waves (and vice versa)" Effectively with minimum loss of signals [18]. Antenna can be classified into four categories biased on:

1. Frequency.
2. Apertures.
3. Polarization.
4. Radiation.

Based on frequency the antenna can be classified in the following categories:

1. Very Low Frequency (VLF) antenna.
2. Low Frequency (LF) antenna.
3. High Frequency (HF) antenna.
4. Very High Frequency (VHF) antenna.
5. Microwave antenna.

An antenna which is operated at microwave frequencies is known as microwave antenna. There are various types of Microwave antenna, and they are used in various applications.Antenna that operate in microwave frequency can be classified into five categories:

1. Microstrip Patch Antenna.
2. Horn Antenna.
3. Parabolic antenna.
4. Plasma antennas.
5. MIMO Antenna.

3.3 Classification of Microstrip Antenna

Microstrip antennas became very popular in the 1970s due to its advantages such as low fabrication coast and small in size. Microstrip Antenna can be classified into three categories:

3.3.1 Microstrip Patch Antenna(MPA)

Theseantennas consist of a metallic patch on a grounded substrate, as shown in **Figure 3.1**. The metallic patch can take many different configurations. However, the rectangular and circular patches, as shown in **Figure 3.2**, are the mostpopular because of ease of analysis and fabrication, and their attractive radiation characteristics. This type can be used these day in government and commercial application[19].

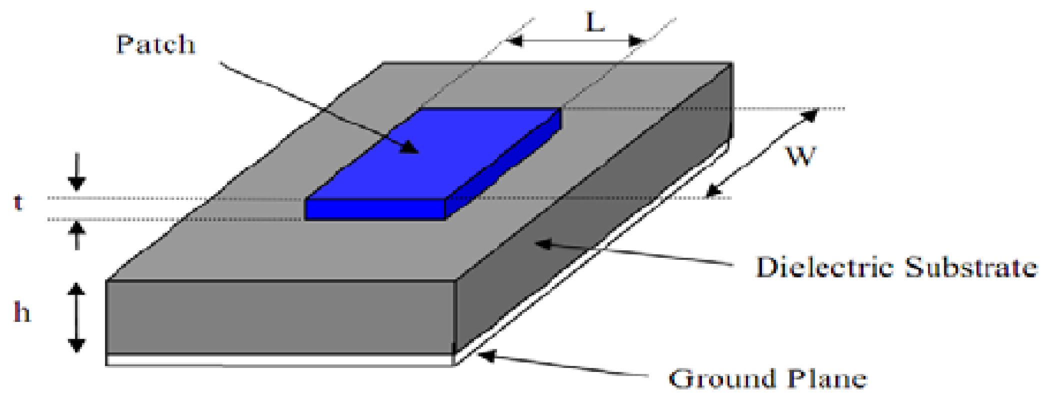


Figure 3.1: Microstrip Patch Antenna.

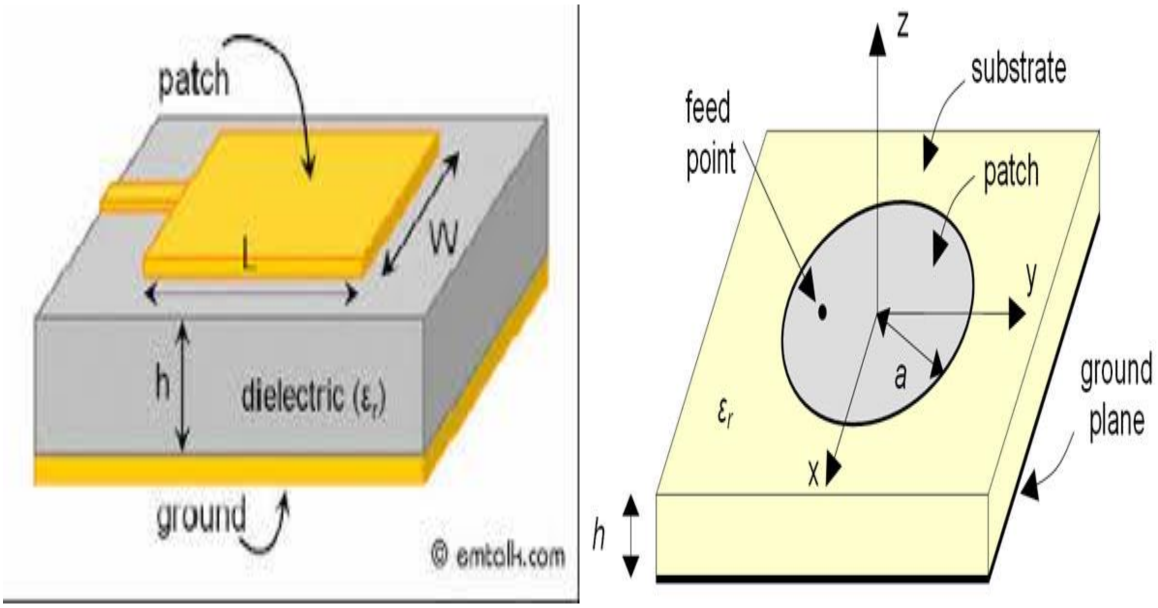


Figure 3.2: Common shape of MPA a.Rectangular Patch Antenna. b.circular patch Antenna

3.3.2 Microstrip Traveling Wave Antenna (MTA)

MTA consists of a chain-of periodic conductors or an ordinary long TEM line which also supports a TE mode, on a substrate backed by a ground plane. The open end of the TEM line is terminated in a matched resistive load. As antenna supports traveling wave, their structures may be designed so that the main beam lies in any direction from broadside to end fire.

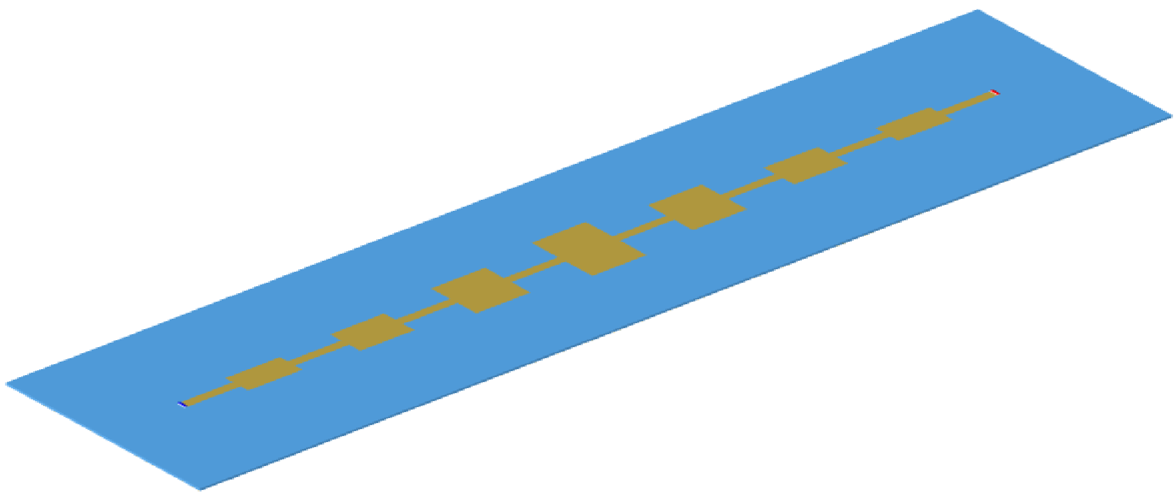


Figure 3.3: Microstrip Traveling Wave Antenna.

3.3.3 Microstrip Slot Antenna

A slot antenna consists of a metal surface, usually a flat plane, with a hole or slot cut into it, as shown in **Figure 3.4**. When the plate is driven as an antenna by a driving frequency, the slot radiates electromagnetic waves in a similar way to a dipole antenna. The shape and size of the slot, as well as the driving frequency, determine the radiation distribution pattern. Slot antennas are typically used at UHF and microwave frequencies when greater control of the radiation pattern is required. The slot antenna is popular because it can be cut out of whatever surface it is to be mounted on, and have radiation patterns that are roughly Omni-directional (similar to a linear wire antenna). The polarization of a slot antenna is linear. Slot antennas are widely used in radar antennas, for the sector antennas, for cell phone base stations, and are often found in standard desktop microwave sources.

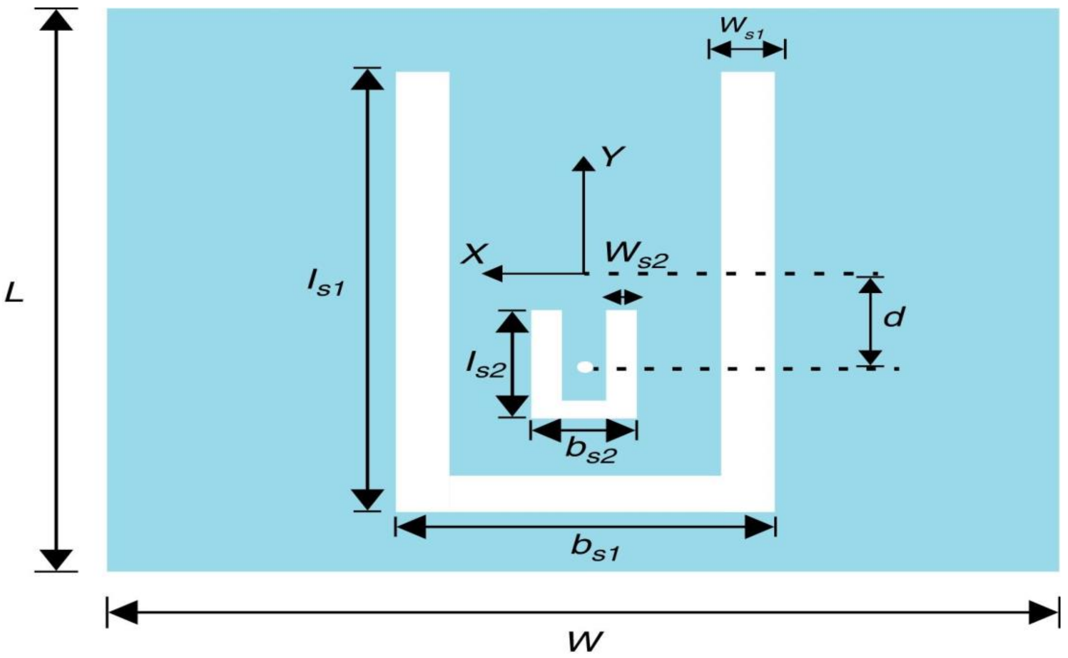


Figure 3.4: U-shaped slot Antenna.

The characteristics of microstrip patch antennas and microstrip slot antennas are compared in **Table 3.1**.

Table 3.1: Comparison between microstrip patch and slot antenna

	Characteristics	**Microstrip Patch Antenna**	**Microstrip Slot Antenna**
1.	Profile	Thin	Thin
2.	Fabrication	Very easy	Easy
3.	Polarization	Both linear and circular	Both linear and circular
4.	Dual-Frequency operation	Possible	Possible
5.	Shape flexibility	Any shape	Mostly rectangular and circular shapes
6.	Spurious radiation	Exists	Exists
7.	Bandwidth	2-50%	5-30%

3.4Application of microstrip Antenna

The microstrip patch antennas are well known for their performance and their robust design, fabrication and their extent usage. The advantages of this microstrip patch antenna are to overcome their advantages such as easy to design, light weight etc., the applications are in the various fields such as in the medical applications, satellites and of course even in the military systems just like in the rockets, aircrafts missiles etc. the usage of the microstrip antennas are spreading widely in all the fields and areas and now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication[20]. It is also expected that due to the increasing usage of the patch antennas in the wide range this could take over the usage of the conventional antennas for the maximum applications. Microstrip patch antenna has several applications. Some of these applications are discussed as below:

3.4.1 Radio Frequency Identification (RFID)

RFID technology is a wireless communication technology that used to uniquely identify tagged objects or people. RFID uses in different areas like mobile communication, logistics, manufacturing, transportation and health care. RFID system generally uses frequencies between 30 Hz and 5.8 GHz depending on its applications. Basically RFID system is a tag or transponder and a transceiver or reader.

Figure 3.5: Microstrip Antenna used in RFID.

3.4.2 Radar Applications

Radar can be used for detecting moving targets such as people and vehicles. It demands a low profile, light weight antenna subsystem, the microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas.

Figure 3.6: Microstrip antenna used in radar.

3.4.3 Global Positioning System applications

Nowadays microstrip patch antennas with substrate having high permittivity sintered material are used for global positioning system. These antennas are circularly polarized, very compact and quite expensive due to its positioning. It is expected that millions of GPS receivers will be used by the general population for land vehicles, aircraft and maritime vessels to find their position accurately.

3.4.4 Worldwide Interoperability for Microwave Access (WiMAX)

The IEEE 802.16 standard is known as WiMAX. It can reach up to 30-mile radius theoretically and data rate 70 Mbps. Microstrip Patch can be generating a 3.4 GHz band and therefore it can be used in WiMAX Application all round the world.

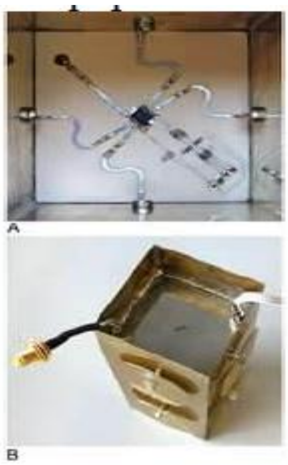


Figure 3.7: Microstrip Antenna used in WiMAX.

3.4.5 Mobile communication application

Due to its advantages, such as small size, low-cost and low profile antenna, microstrip patch Antenna is suitable for Mobile communication. Microstrip patch antenna meets all requirements and various types of microstrip antennas have been designed for use in mobile communication systems.

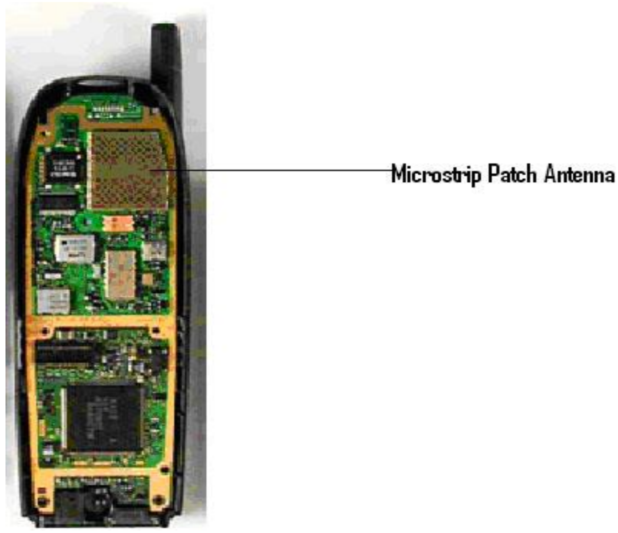


Figure 3.8: Microstrip Antenna used in Mobile communication.

3.4.6 Bluetooth applications

Microstrip patch antenna can be used in Bluetooth communications since it can operate in the range 2400-2484 MHz band. Also the small size of microstrip Patch Antenna make it suitable for this type of communications.

Figure 3.9: Microstrip Patch Antenna used in Bluetooth communications.

Chapter 4

Antenna Characteristics

4.1 Introduction

4.2 Directivity and Gain

4.3 Radiation Pattern

4.4 Return Loss

4.5 Bandwidth

4.6 Polarization

4.7 Antenna Impedance

Chapter 4

Antenna Characteristics

4.1 Introduction

Every device has its own characteristics, as well, antenna has its own characteristics that must be known to understand the behavior of the antenna and study its performance. Antenna has several characteristics such as, directivity, gain, radiation pattern, radiation resistance, and many others. In this chapter, we are going to study those characteristics.

4.2 Directivity and Gain

One very important quantitative description of an antenna is how much it concentrates energy in one direction in preference to radiation in other directions. This characteristic of an antenna is called directivity and is equal to its gain if the antenna is 100% efficient. Gain is expressed relative to an isotropic radiator or sometimes a half-wavelength dipole[21].

We know that

$$P = \iint S.ds = \frac{1}{2} Re \iint (E \times H^*).ds \qquad \text{Equation (4.1)}$$

$$H_{\emptyset} = \frac{E_\theta}{\eta} \qquad \text{Equation (4.2)}$$

And

$$H_\theta = -\frac{E_\phi}{\eta} \qquad \text{Equation (4.3)}$$

Substituting (2.11) and (2.12) in (2.10), we get

$$p = \frac{1}{2\eta} \iint \left(|E_\theta|^2 + \left|E_\phi\right|^2 \right) r^2 d\Omega \qquad \text{Equation (4.4)}$$

Where dΩ = element of solid angle = sin θ dθdϕ, which is shown in the figure.

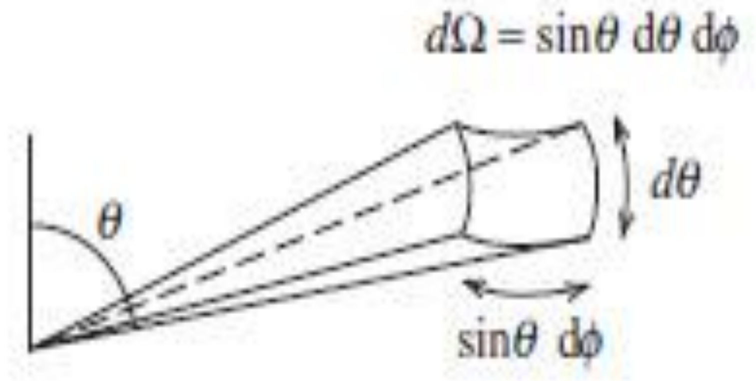


Figure 4.1: Element of solid angle.

The integral can be evaluated over any surface enclosing the antenna; however, for simplicity a spherical surface centered on the origin is usually used. Since the magnitude variations of the radiation fields are 1/r, we find it convenient to introduce radiation intensity, which is defined from[21]

$$U(\theta, \phi) = \frac{1}{2} Re(E \times H^{*}).r^{2}.\hat{r} = S(\theta, \phi) r^{2} \qquad \text{Equation (4.5)}$$

Radiation intensity is the power radiated in a given direction per unit solid angle and has units of watts per square radian (or steradian, sr). The advantage to using radiation intensity is that it is independent of distance r. Radiation intensity can be expressed as

$$U(\theta, \phi) = U_{m} |F(\theta, \phi)|^{2} \qquad \text{Equation (4.6)}$$

Where Um is the maximum radiation intensity.

The total power radiated is obtained by integrating the radiation intensity over all angles around the antenna:

$$P = \iint U(\theta, \phi) d\Omega = U_{m} \iint |F(\theta, \phi)|^{2} d\Omega \qquad \text{Equation (4.7)}$$

where $|F(\theta, \phi)|^{2}$ is the power pattern normalized to maximum value of unity in the direction (θ_{max} , ϕ_{max}).

Directivity is defined as the ratio of the radiation intensity in a certain direction to the average radiation intensity. The reference direction is usually taken to be that of the maximum radiation, giving

$$D = \frac{U_m}{U_{avg}} = \frac{U_m}{p/4\pi} \qquad \text{Equation (4.8)}$$

Gain is defined as 4π times the ratio of the maximum radiation intensity to the net power accepted by the antenna from the connected transmitter, or

$$G = \frac{4\pi U_m}{P_m} \qquad \text{Equation (4.9)}$$

4.3 Radiation Pattern

Radiation pattern of the antenna is a plot of the far-fields radiated from the antenna, that is, it's a plot of the power radiated for the antenna per unit solid angle[22]. This is arrived at by simply multiplying the power density at a given distance by the square of the distance r, where the power density S [watts per square meter] is given by the magnitude of the time-averaged Poynting vector:

$$U = r^2 S \qquad \text{Equation (4.10)}$$

This has the effect of removing the effect of distance and of ensuring that the radiation pattern is the same at all distances from the antenna, provided that r is within the far field. The simplest example is an idealized antenna which radiates equally in all directions, an isotropic antenna. If the total power radiated by the antenna is P, then the power is spread over a sphere of radius r, so the power density at this distance and in any direction is[22]

$$S = \frac{P}{area} = \frac{P}{4\pi r^2} \qquad \text{Equation (4.11)}$$

The radiation intensity is then

$$U = r^2 S = \frac{P}{4\pi} \qquad \text{Equation (4.12)}$$

There are some parameters used to compare radiation patterns are defined as follows[22]:

- The *half-power beamwidth* (HPBW), or commonly the beamwidth, is the angle subtended by the half-power points of the main lobe. The pattern of the Hertzian dipole falls by onehalf at _ ¼ _=4 and _ ¼ 3_=4, so its half-power beamwidth is _=2 ¼ 90.
- The *front-back ratio* is the ratio between the peak amplitudes of the main and back lobes, usually expressed in decibels.
- The *sidelobe level* is the amplitude of the biggest sidelobe, usually expressed in decibels relative to the peak of the main lobe.

The mentioned parameters are shown in the **Figure 4.2**.

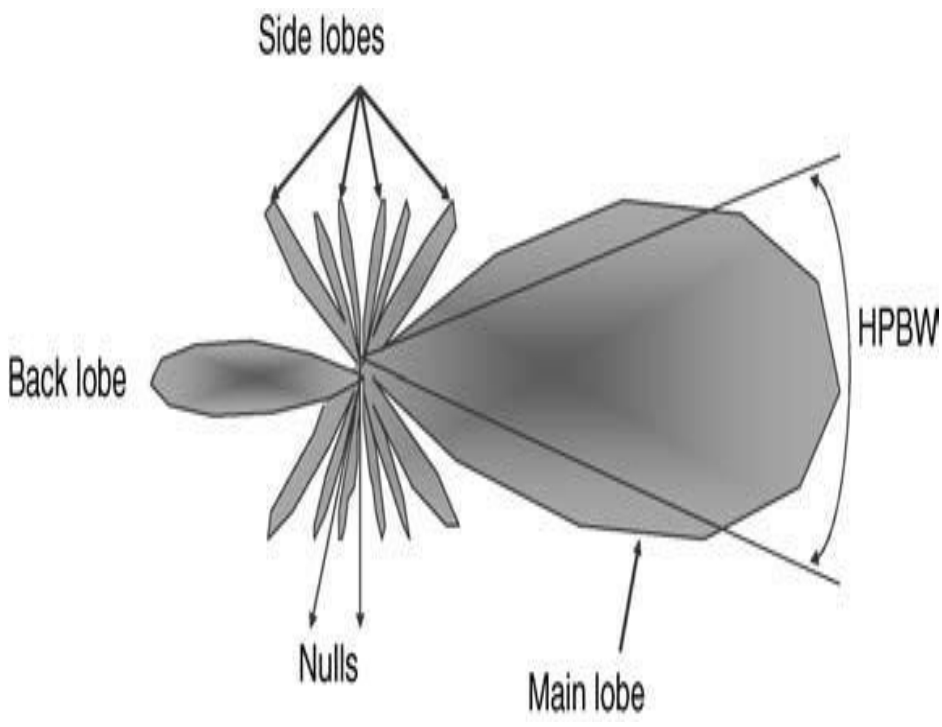


Figure 4.2: Radiation pattern of a generic antenna.

4.4 Return Loss

Return Loss determines the matching properties of antenna. It indicates that how much efficiently antenna is transmitting/receiving electromagnetic wave over particular band of frequencies. It is also a measure of the effectiveness of an antenna to deliver of power from source to antenna.

Return Loss is defined as the ratio of the incident power of the antenna to the power reflected back from the antenna of the source and it is given by:

$$RL = 10\log_{10}\frac{P_{ref}}{P_{in}} \qquad \text{Equation (4.13)}$$

It is must be noticed that the higher the reflection coefficient is, the more efficient the antenna is.

4.5 Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1.

The bandwidth can also be described in terms of percentage of the center frequency of the band.

$$BW = \frac{FH-FL}{FC} * 100\% \qquad \text{Equation (4.14)}$$

Where FH is the highest frequency in the band, FL is the lowest frequency in the band, and FC is the center frequency in the band. In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

4.6 Polarization

The microstrip Patch Antenna radiated a waves in a different direction, the orientation of the lines of electric flux in an electromagnetic field is called Polarization. When the direction of propagation is not specified, the polarization will be in the direction of the maximum radiation. The polarization depends on the type of feeding method used to feed microstrip Patch Antenna [24]. The most popular polarization type is:

4.6.1 Linear Polarization

A slot antenna is the counterpart and the simplest form of a linearly polarized antenna. On a slot antenna the E field is orientated perpendicular to its length dimension. The usual microstrip patches are just different variations of the slot antenna and all radiate due to linear polarization. **Figure 4.3** illustrates the operations of a linearly polarized wave radiating perpendicular to the patch plane.

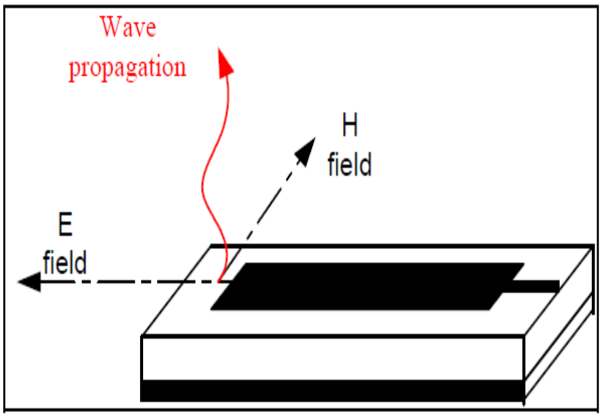


Figure 4.3: Linear Polarization.

4.6.2 Circular Polarization

Circular polarization is usually a result of orthogonally feed signal input. When two signal of equal amplitude but 90 phase shifted, then the resulting wave is circularly polarized Circular, as shown in **Figure 4.4**. Circular polarization is achieved through radiating elements like square, circular and triangular patches either through single fed or double fed feeding techniques. The circularly polarized antennas are helpful in reducing multipath fading due to which spectral efficiency, impedance and axial bandwidth of RF system is increased. The data transmission in circular polarization does not depend on the orientation of the transmitter and receiver. The incoming waves of any polarization can be received with a left hand circularly polarized antenna but in the case of right hand circularly polarized antenna it is vice-versa. In these days, wireless communication system use circular polarization because it can provide better mobility, weather penetration, flexibility in orientation angle and reduction in multipath reflection as compared to linear polarization[23].

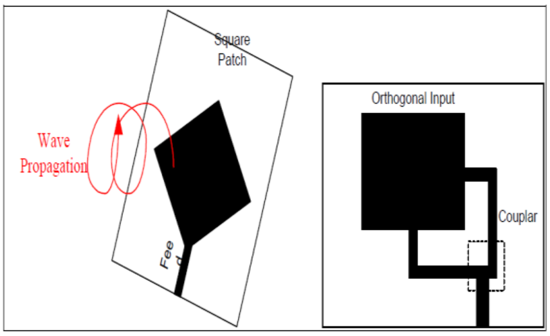


Figure 4.4: Circular polarization.

4.7 Antenna Impedance

Any transmitting antenna has a main and key function, that is, converting a bounded wave to an unbounded (i.e., radiated) wave, and vice versa for a receiving antenna. Whereas the transmission line connected to an antenna binds the wave and prevents it from radiating, the antenna itself should instead enable radio waves to leave the structure [12]. The antenna is an interface between wave phenomena on and beyond the antenna to the connecting circuit hardware. The antenna input terminals form the interface point and the circuit parameter of impedance is used to characterize the input to the antenna. The input impedance of an antenna (or simply antenna impedance) will be affected by other antennas or objects that are nearby, but the discussion here assumes an isolated antenna, as shown in **Figure 4.5**.

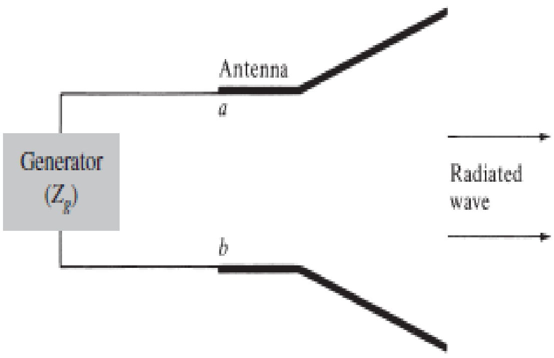


Figure 4.5: general antenna model

From circuit point of view, input impedance of an antenna can be expressed as[12]:

$$Z_A = R_A + jX_A \qquad \text{Equation (4.15)}$$

Where:

ZA = antenna impedance at terminals *a*–*b* (ohms)

RA = antenna resistance at terminals *a*–*b* (ohms)

XA = antenna reactance at terminals *a*–*b* (ohms)

In general, the resistive part of (4.15) consists of two components; that is

$$R_A = R_r + R_L \qquad \text{Equation (4.16)}$$

Where:

Rr= radiation resistance of the antenna

RL = loss resistance of the antenna

Assume that the antenna is attached to a generator with internal impedance of:

$$Z_g = R_g + jX_g \qquad \text{Equation (4.17)}$$

where

Rg= resistance of generator impedance (ohms)

Xg= reactance of generator impedance (ohms)

We can represent the antenna and generator by an equivalent circuit shown in **Figure 4.6**.

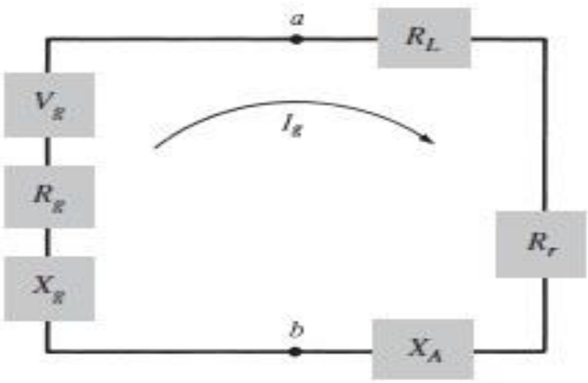


Figure 4.6: Antenna and generator by an equivalent circuit

It is obvious from the figure that the current in the loop is given by[12]:

$$I_g = \frac{V_g}{Z_Z+Z_g} = \frac{V_g}{R_r+R_L+R_g+j(X_A+X_g)}$$ Equation (4.18)

The power delivered to the antenna for radiation is given by

$$P_r = \frac{|V_g|^2}{2}\left[\frac{R_r}{(R_r+R_L+R_g)^2+(X_A+X_g)^2}\right]$$ Equation (4.19)

The maximum power delivered to the antenna occurs when we have conjugate matching; that is when

$$Rr + RL = Rg$$ Equation (4.20)

$$XA = -Xg$$ Equation (4.21)

The power supplied by the generator during conjugate matching is

$$P_s = \frac{|V_g|^2}{4}\left[\frac{1}{R_r+R_l}\right]$$ Equation (4.22)

Half of the power supplied by the generator is dissipated as heat in the internal resistance (*Rg*) of the generator and the other half is delivered to the antenna. This only happens when we have conjugate matching.

Chapter 5

Design and Simulation

5.1 Brief Introduction

5.2 Design component

5.3 Conceptual Design

5.4 Procedure

Chapter Five

Design and Simulation

5.1 Brief Introduction

Recently, there are rapid developments in wireless communications, and in order to satisfy the IEEE 802.11 WLAN standards in the 2.4GHz (2400-2484 MHz) and WiMAX 3.5GHz (3.4GHz- 3.66GHz) bands, dual band and triple band operations the printed monopole antennas are required. For available designs, the microstrip antennas [MSAs] are widely used due to their attractive features such as light weight, low profile, ease in fabrication and low cost.

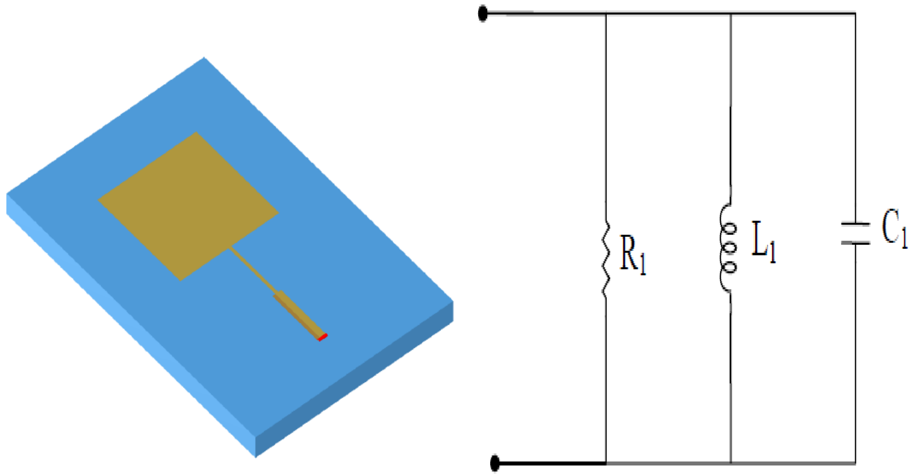
5.2 Design Components

In order to design a microstrip patch antenna, there are several essential parameters must be taken in consideration that affect the antenna performance such as the frequency of operation (f), the dielectric constant of the substrate, and the height of the dielectric substrate(h).

5.3 Conceptual Design

The development of multi-band Microstrip antenna has received much attention in recent years. In normal patch antenna the multi-band is hard to obtained so the slot technique is used to overcome the need of multi-band of frequencies. The U-slot techniques are one of the popular techniques to obtain the dual band operation. Dual resonance is obtained by introducing the single U-slot to the radiating edge of the patch. In order to get more than two band of frequencies such as quad band, two U-slots must introduce in the radiating patch [24].

In its simple form microstrip antenna is considered as a parallel combination of resistance(R), inductance (L) and capacitance (C). The simple patch antenna and its equivalent circuit can be given as shown in **Figure 5.1**.



(a) (b)

Figure 5.1 a. simple patch antenna. b. Equivalent circuit of patch.

A U-slot loaded patch is analyzed by considering two sections in the patch. First section is an E-shaped patch [24] and second (lower one) as microstrip bend line as shown in **Figure 5.2.**

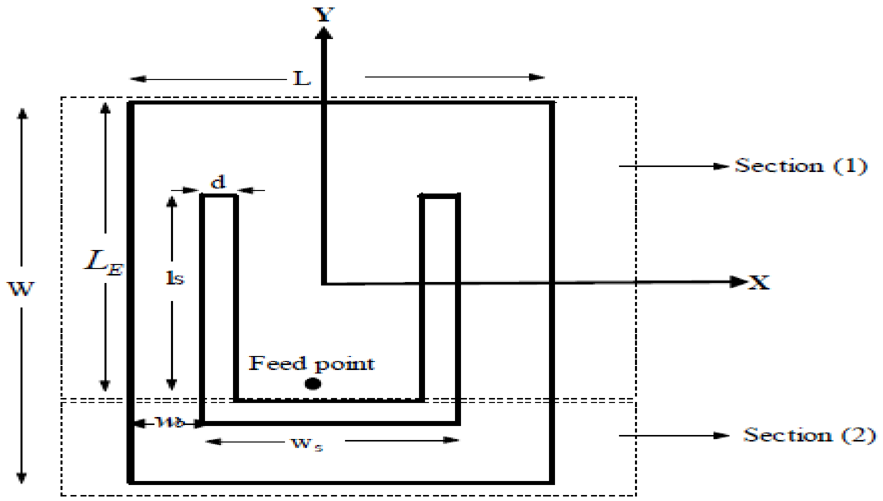


Figure 5.2: U-slot loaded patch.

The following figure explain the equivalent circuit of section 1.

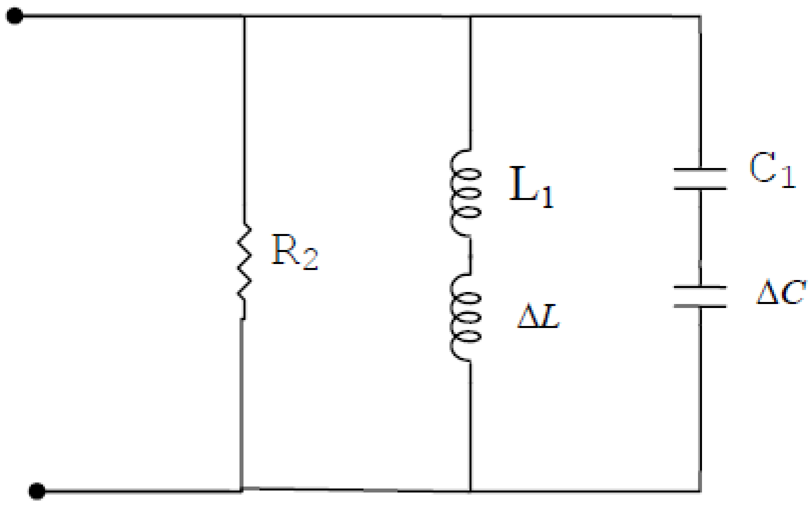


Figure5.3: Equivalent circuit of section (1).

The second section is considered as two microstrip bend line and the equivalent impedance of this shape is given as [24]

Zb = jwLb + 1/(1/jwLb) + jwCb. Equation (5.1)

The equivalent model of combining the above two section is given in the following figure. This model will produce dual band properties.

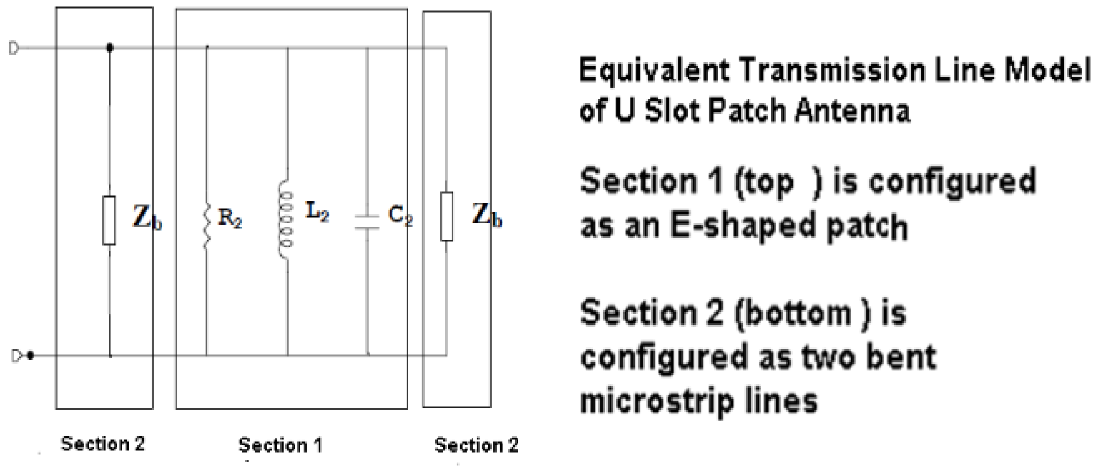


Figure 5.4: Equivalent circuit of U-slot loaded patch

5.4 Procedure

This sectionpresents the methodology of designing Microstrip antenna. To achieve our goals in this work, we will follow the flow chart in figure 1.5 in page 6, which explain our methodology in this project.

5.4.1 Phase I

Step 1: **Determine Operating Frequency:**

Operating frequency is the frequency at which the communications are being made with the total bandwidth occupied by the carrier signal with modulation. Usually bandwidth of the antenna will be wider than the bandwidth of the signal so that more than one center frequency the antenna can be put in to effective use. Since dual and multiband become an interesting topic these days because it can be used for several applications in the same time. In this work, our goal is to design antenna that operate at different frequency which are 1.8 GHz which can be used for GSM, 2.4 GHz which can be used in Wi-Fi application, and 3.5 GHz which can be used in WiMAX application.

Step 2: Determine Dielectric Material:

The second step in designing microstrip antenna is to choose the suitable substrate. There are various types of substrate available in market that provides considerable flexibility in the choice of a substrate for particular applications. For good antenna performance, a dielectric with low value but high thickness is required, as this provide better efficiency, larger bandwidth and better radiation. However, such a design leads to antenna of larger size. In order to reduce the size, a higher dielectric constant should be used, but this results in a microstrip with less efficiency and narrow bandwidth due to its high quality factor. in our design the dielectric material is Flame Retardant (FR-4) which is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant, with the dielectric constant equal 4.4, this material is relatively low in cost for such low loss tangent. Since the electric filed line are moving into the air before entering the dielectric substrate as shown in figure 5.5, the $\boldsymbol{\varepsilon r}$ will be replaced by the effective dielectric constant($\boldsymbol{\varepsilon reff}$). In order to calculate the effective dielectric constant, Equation 2.1 is used.

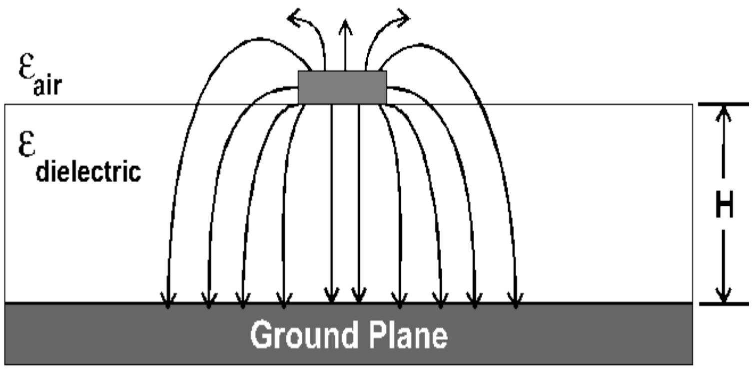


Figure 5.5: Electric field line

Step3: determine dimension of the antenna:

Since current product has a small size such as personal communication service such as mobile phone and WLAN, this lead to challenge in antenna design, so modern antenna must have a small size to be placed inside minimized wireless communication system. The second step in this design is to calculate the length(L) and the Width(W) of the antenna, as shown in Figure 5.6. In order to achieve this object, the following equations are used:

- To calculate the width:

$$W=\frac{1}{2\,fr\sqrt{\mu o\varepsilon o}}\sqrt{\frac{2}{\varepsilon r+1}}=\frac{Vo}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \qquad \text{Equation (5.2)}$$

- To calculate the extended Length (ΔL):

$$\Delta L=0.412*h*\frac{(\varepsilon reff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{W}{h}+0.8)} \qquad \text{Equation (5.3)}$$

- To calculate the Length:

$$L=\frac{1}{2fr\sqrt{\varepsilon reff}\sqrt{\mu o\varepsilon o}}-2\Delta L \qquad \text{Equation (5.4)}$$

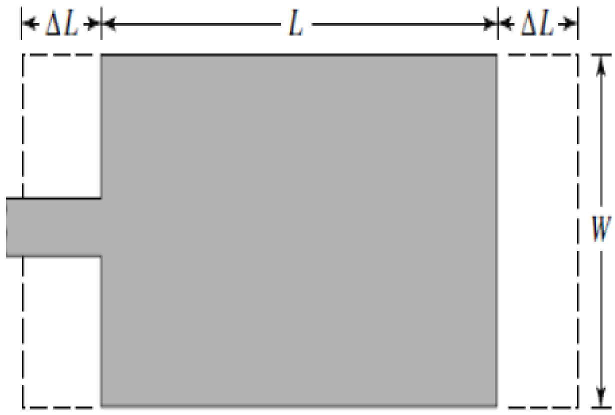


Figure 5.6: Physical and effective length of a microstrip antenna.

- determine **height** of the antenna:

Since current product have a small size such as personal communication service such as mobile phone and WLAN, this lead to challenge in antenna design. For the microstrip patch antenna to be used in cellular phones, it is essential that the antenna is not bulky. In our work we choice the suitable height to be 1.6mm.

Step4: **Feeding method:**

For efficient transfer of energy, the impedance of antenna and the transmission line connecting the antenna must be the same. Efficient antenna configurations often have an impedance other than 50 Ohms. Some sort of impedance matching circuit is then required to transform the antenna impedance to 50 Ohms. In our design the impedance matching is 50 ohms, and it was calculated Using CST, as shown in **Figure 5.7**.

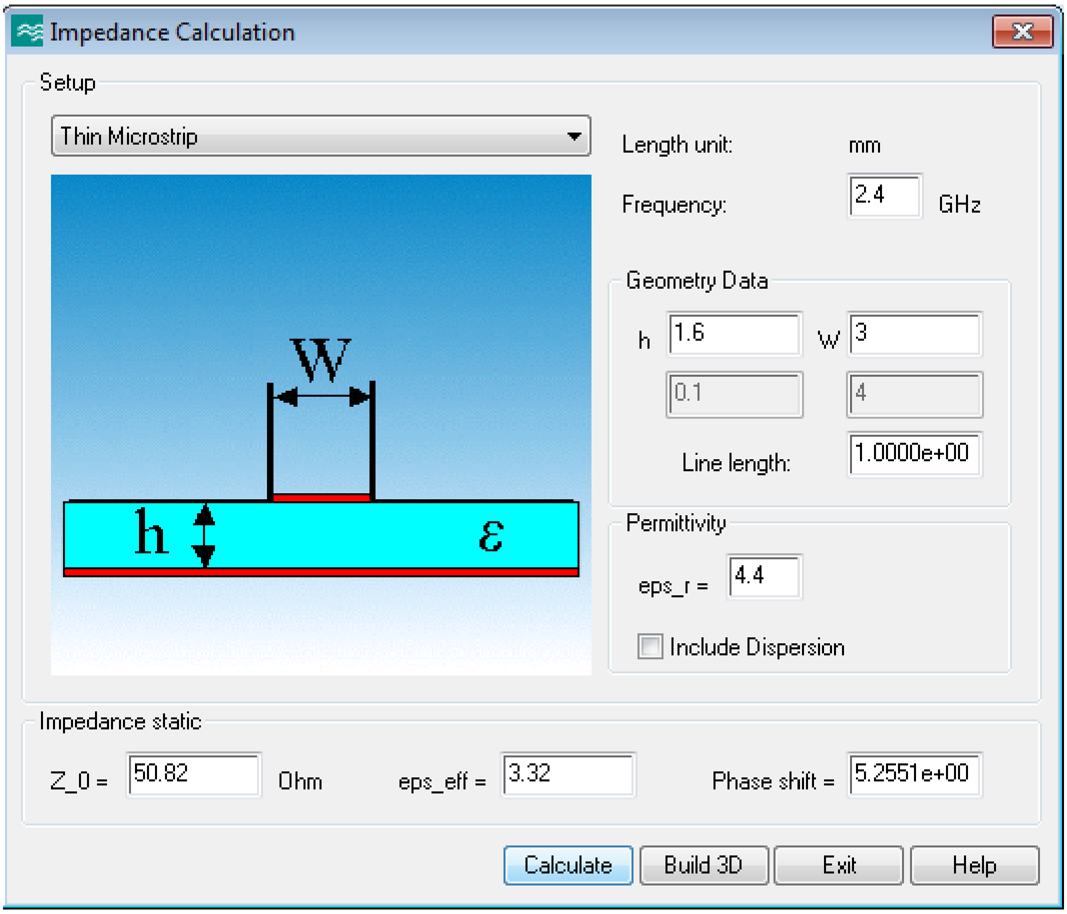


Figure 5.7: Impedance Calculation Using CST studio.

5.4.2Phase II Software Design

In this section we will explain step 5 in the methodology flow chart. We will explain our work to build our design in a brief step because long and hard work out was done to achieve this design.

Step1:

We first build a rectangular microstrip antenna as shown in **Figure 5.8**, Using Computer Simulation Technology (CST). software, available at the Microwave and Antenna System Laboratory.

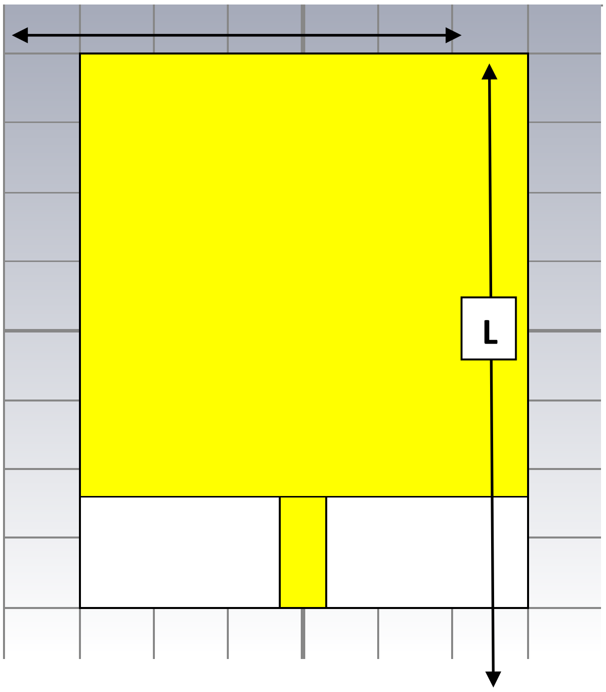


Figure 5.8: Rectangular MPA.

Step 2:

In order to achieve a multi resonant frequency as our goals in this project, the idea of using slots on the patch is used, as shown in **Figure 5.9**.

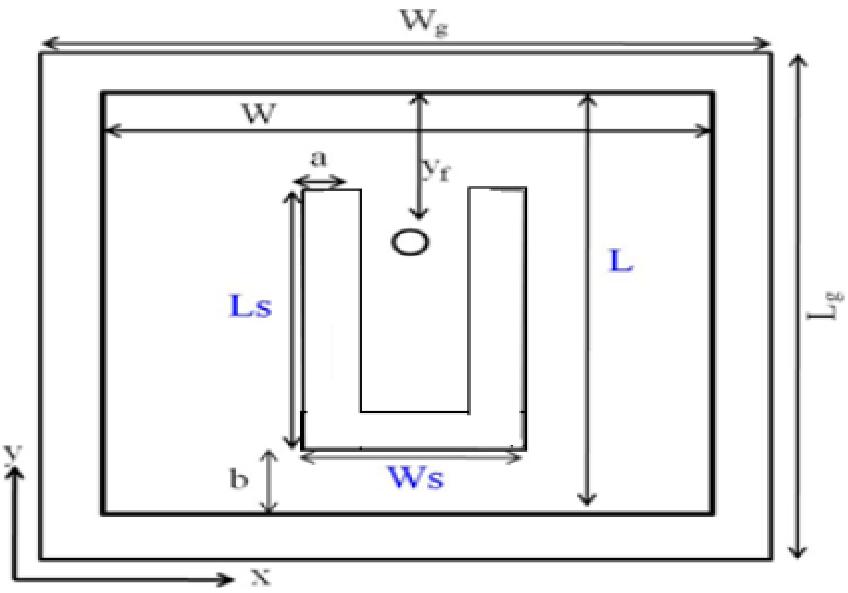


Figure 5.9: Using slots in the patch.

Step 3:

In order to design the proposed antenna, one important thing is to design microstrip feed line. There is a relationship between the dimensions of the line and the equivalent RLC components. The following figure shows the microstrip feed line.

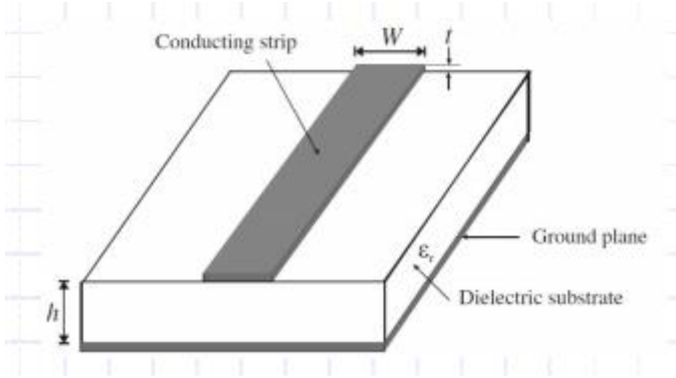


Figure 5.10: microstrip feed line.

The capacitance of the line is depending on the width and length of the line also it depends on the distance which represent the thickness of the dielectric material as in the following equation.

$$C=\frac{\varepsilon\varepsilon_0(W*L)}{d} \quad \text{Equation (5.5)}$$

Where:

εr:represent the relative permeability of the dielectric material multiply with relative permeability of the air.

W: is the width of the microstrip line.

L: is the Length of the line.

d: thickness of dielectric material.

Based on the above equation, the capacitance of the microstrip lineincrease by increase the width and length of the line, while its decrease by increase the distance (thickness) of the dielectric material.

The resistance of the line is depending on the length and areof the line also as in the following equation

$$R=\frac{\rho L}{A} \quad \text{Equation (5.6)}$$

Where:

ρ: resistivity of the copper.

L: is the length of the line.

A: is the cross section of the line.

The resistance of the line increase by increase the length of the line, and its decrease by the decrease of the line area.

The conductance of the line is depending on the length and areof the line also as in the following equation

$$L(nH)=2 * 10^{-4} L \left[\ln\left(\frac{L}{W+t}\right) + 1.193 + 0.2235\, W + \frac{t}{L}\right] . Kg \quad \text{Equation (5.7)}$$

Where:

L: length of the line.

L(nH): inductance of the line.

W: width of the line.

t: thickness of the line.

The U-slot idea is first studied in reference [24]. By using a single U slot in the patch the double resonant frequencies are generated. Based on figure 5.4, the single U-slot can be considered as two section, the first section is configured as an E-shaped patch and the second section is considered as two bent microstrip lines. The total model of single U- slot can provide two resonant frequencies.In the design we initially used a single slot in the patch with the initial dimensions as in [24] which is represented in the following table. While the width(W) and length(L) and the width(W of the antenna is calculated using equations 5.2 and 5.4 respectively.

Table 5.1: initial values of the first U-slot in mm.

L1	W1	T2	W	L
32	4	4	30	40

The dimensions of the slot is generated by the analysis of the effect of each dimension on the resonant frequencies. Then we insert another U-slot in order to achieve multi-band characteristics with initial value as in the following table by take the length of the slot, double the width of the slot and make the thickness half of the thickness as in [24].

Table 5.2: initial values of the second U-slot in mm.

L3	W2	T1
32	8	2

FR4_epoxy (dielectric constant = 4.4 and height = 1.6mm) is used as substrate to design the proposed U-slot microstrip patch antenna. the position of the U-slot in the patch was a serious convention in the design, since in order to get the compatibility between the two slot and the desired operation frequency, a good position of slot in the patch is required. The geometry of the proposed antenna is shown in **Figure 5.11(a)**, **Figure 5.11(b)**, and **Figure 5.11(c)**. The dimension of the antenna is 40x30x1.6 mm^3.

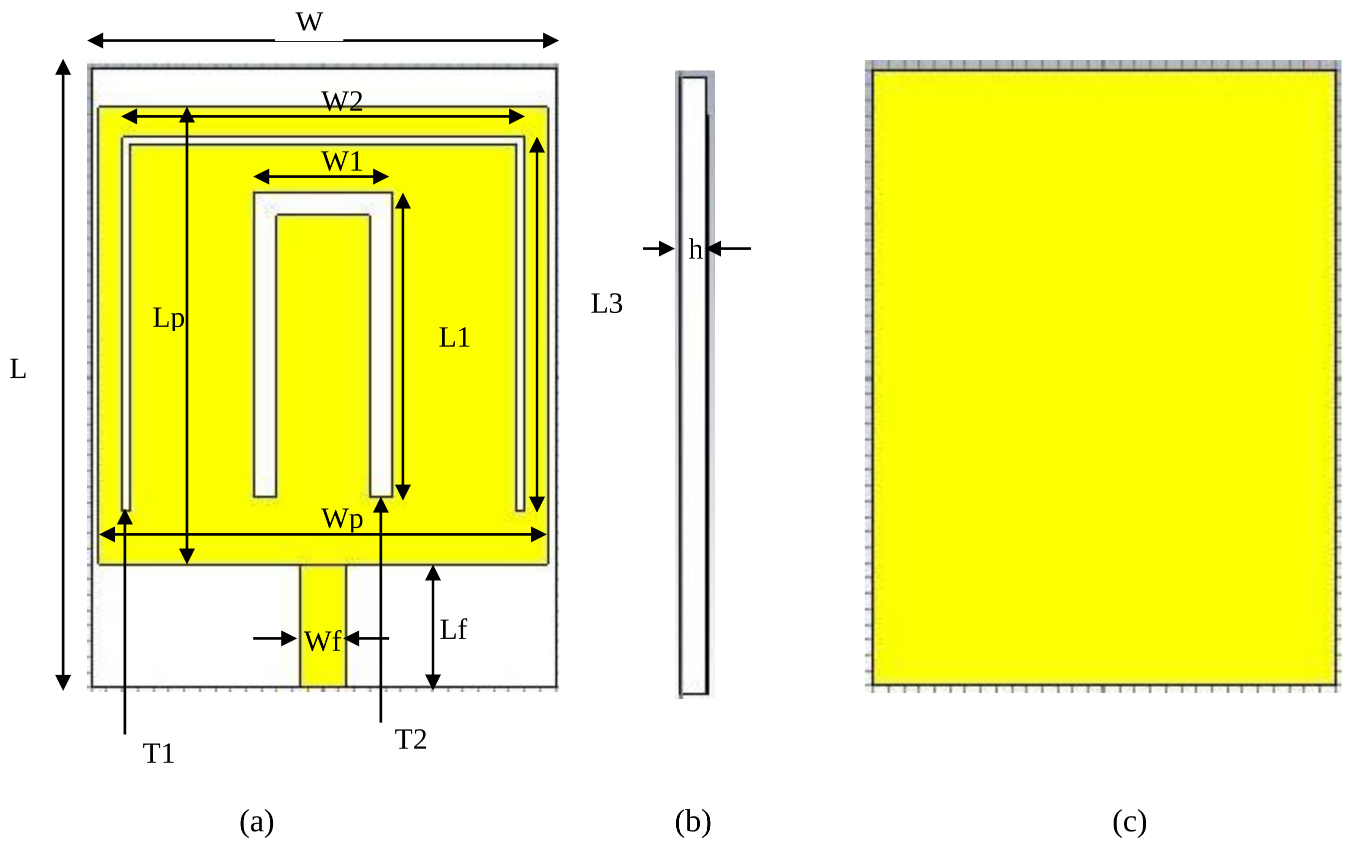


Figure 5.11: The geometry of the proposed antenna, a. Front view, b. Side view, c. Back view.

Table 5.3: Value of the desired parameters.

Parameter	W	L	W2	L1	W1	L3	Wf	Wp	Lp	T1	T2	Lf	H
Units (mm)	30	40	26	19.7	9	24.2	3	29	29.5	0.5	1.5	8	1.6

The initial parameters in table 5.1 and 5.2 is changed in order to achieve our goals of the project .since the resonant frequency depend on the dimensions of the slot, the parameters in table 5.3 is selected.

5.4.3 Phase III Frequency Control

In this section we will explain how we control the resonant frequency by using length and width of the slots in our design in order to get specific resonant frequency at the desired value.

Step1: Control resonant frequency at 3.5 GHz:

Based on the current distribution at 3.5 GHz we determine the dominant slot in order to control resonant frequency at 3.5 GHz as shown in **Figure 5.12** below. The resonant frequency at 3.5 GHz can be controlled using the length of the external slot(L3).

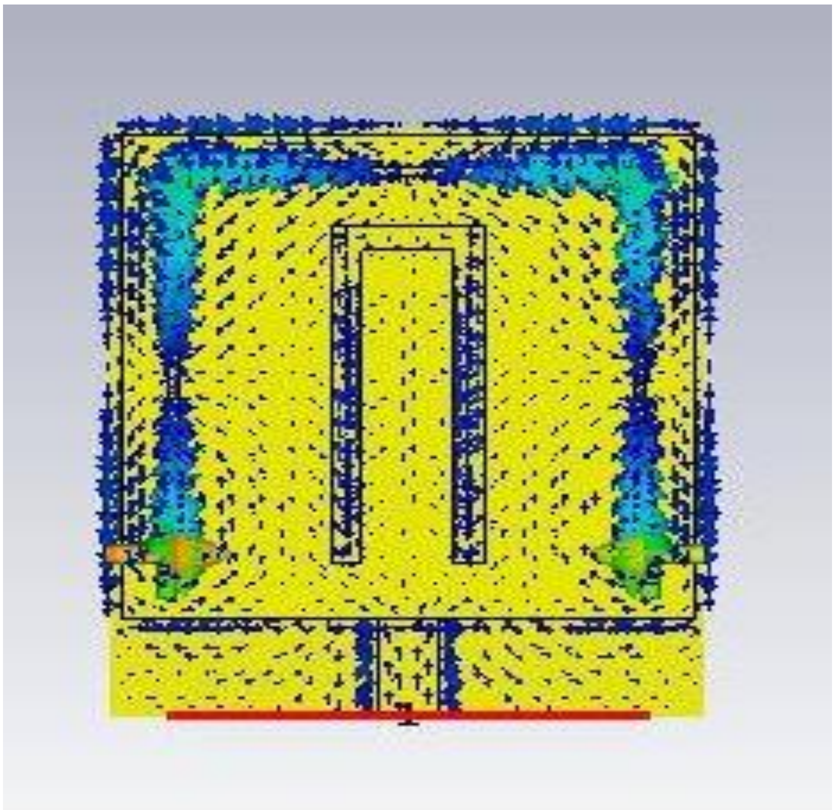


Figure 5.12: current distribution at 3.5 GHz.

Figure 5.13show the desired parameter.

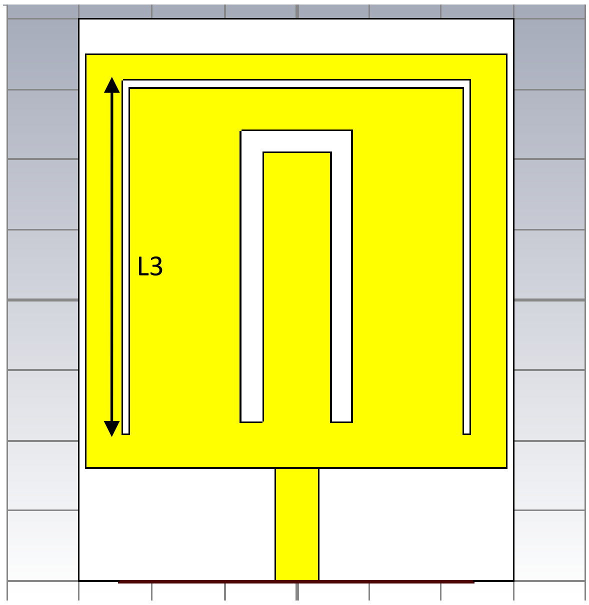


Figure 5.13: Desired Parameter L3.

As shown in the **Figure 5.14** below, the resonant frequency at 3.5 GHz was successfully controlled using L3, without affect the other resonant. When L3 is varied from 24.2 mm to 22.2 mm, the resonant frequency at 3.5 GHz varies from 3.5 to 3.6 GHz, while the 1st and the 2nd resonant remains fixed.

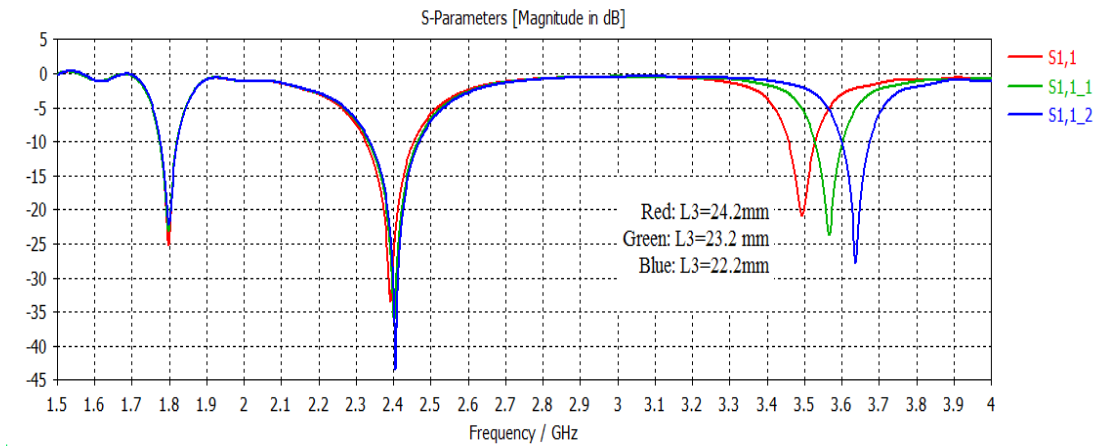


Figure 5.14: Variation of the resonant frequency by reducing L3.

As shown in the **Figure 5.15** below, the resonant frequency at 3.5 GHz was successfully controlled using L3, without affect the other resonant. When L3 is varied from 24.2 mm to 26.2 mm, the resonant frequency at 3.5 GHz varies from 3.5 to 3.35 GHz, while the 1st resonant remain fixed. In this case the 2nd resonant is varied little.

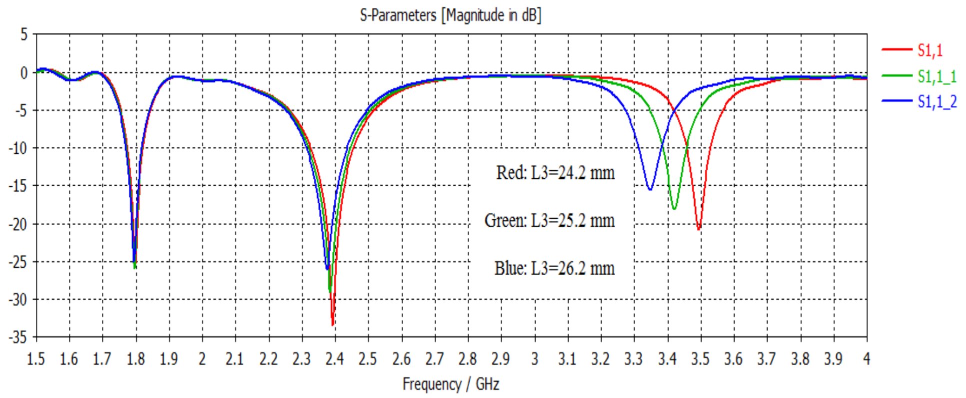


Figure 5.15: Variation of the resonant frequency by increased L3.

Step2: Control resonant frequency at 1.8 GHz:

Based on the current distribution at 1.8 GHz we determine the dominant slot in order to control resonant frequency at 1.8 GHz as shown in **Figure 5.16** below.The resonant frequency at 1.8 GHz can be controlled using the length of the internal slot (L1) and the width (W1).

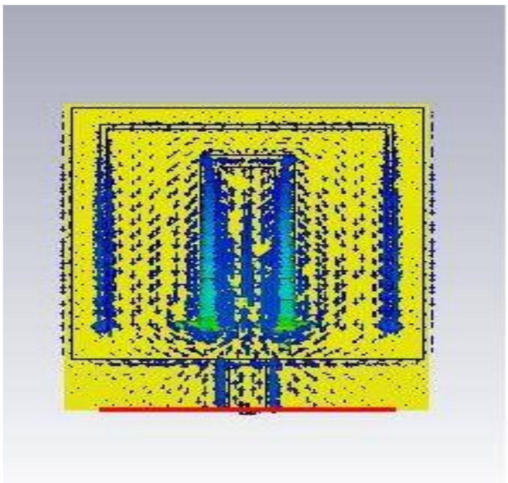


Figure 5.16:current distribution at 1.8 GHz.

- Using L1:

Figure 5.17 show the desired parameter.

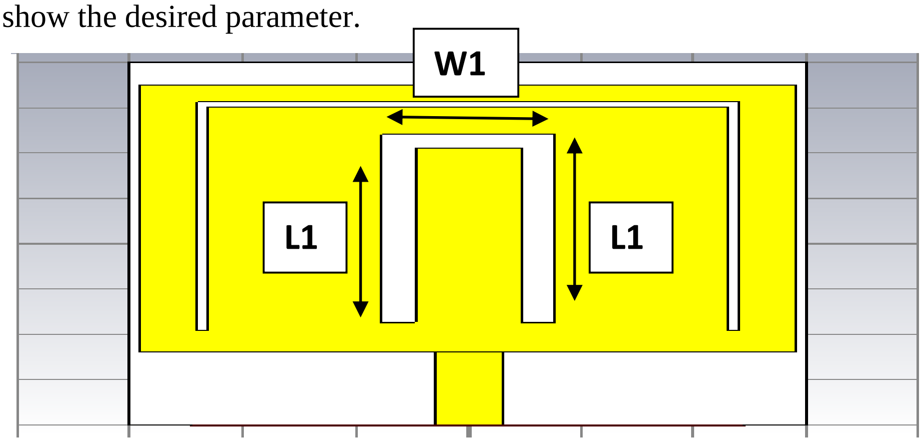


Figure 5.17: Desired Parameter L1.

As shown in the **Figure 5.18** below, the resonant frequency at 1.8 GHz was successfully controlled using L1. When L1 is varied from 20.7 mm to 18.7 mm, the resonant frequency at 1.8 GHz varies from 1.8 to 1.93 GHz, while the 3rdresonant remain fixed. In this case the 2nd resonant is varied little.

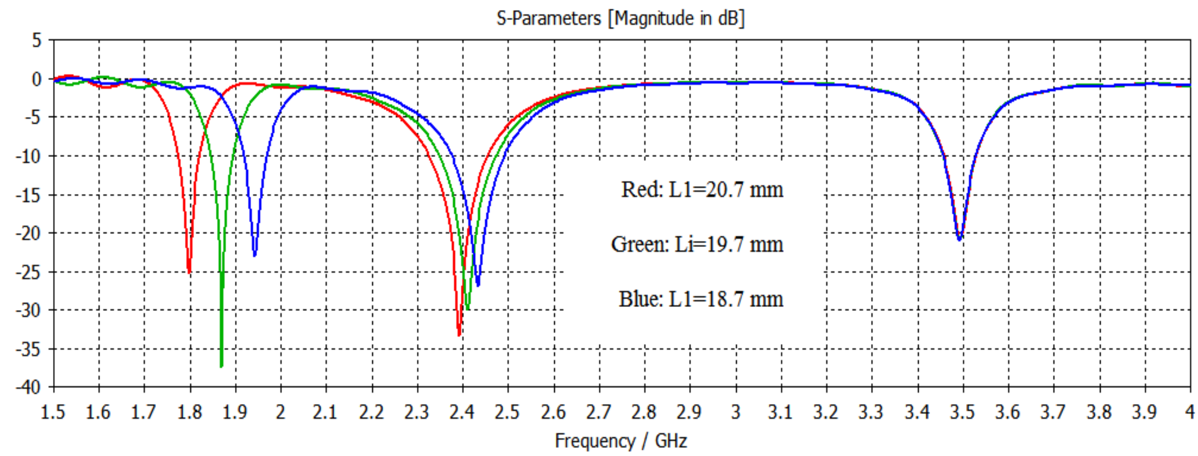


Figure 5.18: Variation of the resonant frequency by decreasing L1.

As shown in the **Figure 5.19** below, the resonant frequency at 1.8 GHz was successfully controlled using L1. When L1 is varied from 20.7 mm to 22.7 mm, the resonant frequency at 1.8 GHz varies from 1.65 to 1.8 GHz, while the 3rd resonant remain fixed. In this case the 2nd resonant is varied little.

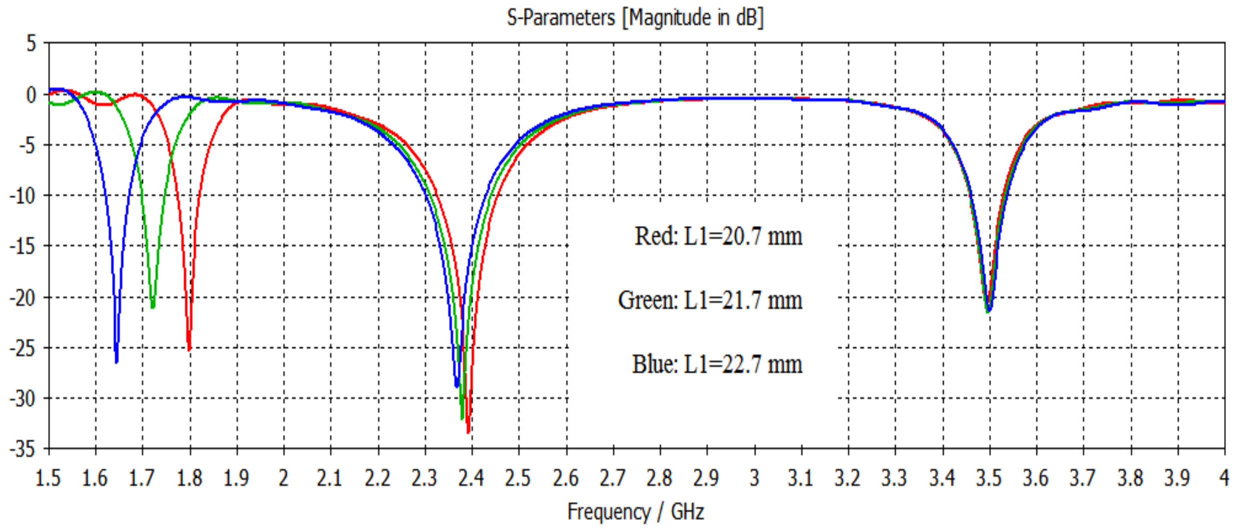


Figure 5.19: Variation of the resonant frequency by increasing L1.

- Using W1:

As shown in the **Figure 5.20**, the resonant frequency at 1.8 GHz was successfully controlled using W1. When W1 is varied from 7.7 mm to 9.7 mm, the resonant frequency at 1.8 GHz varies from 1.7 to 1.8 GHz, while the 2nd and the 3rd resonant remain fixed.

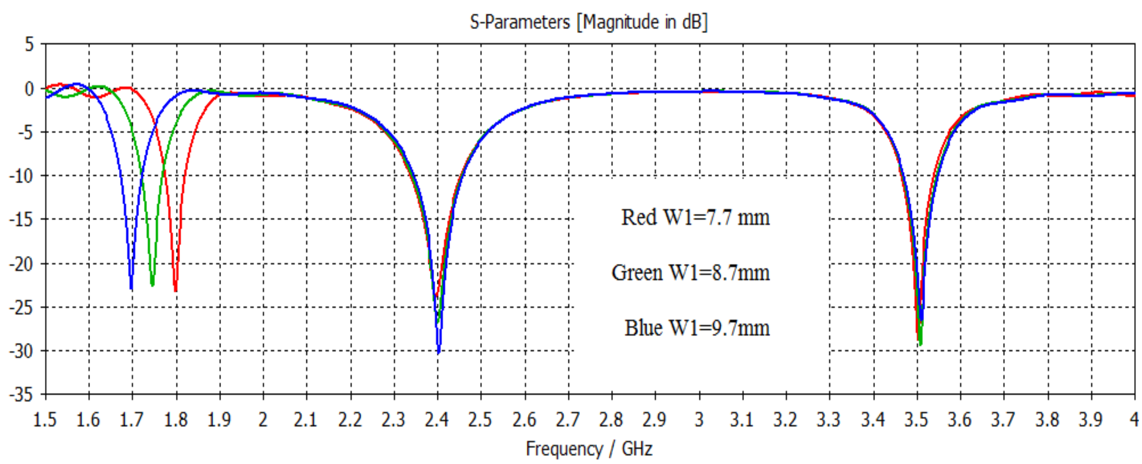


Figure 5.20: Variation of the resonant frequency by increasing W1.

As shown in the **Figure 5.21** below, the resonant frequency at 1.8 GHz was successfully controlled using W1. When W1 is varied from 7.7 mm to 5.7 mm, the resonant frequency at 1.8 GHz varies from 1.8 to 1.92 GHz, while the 2nd and the 3rd resonant remain fixed.

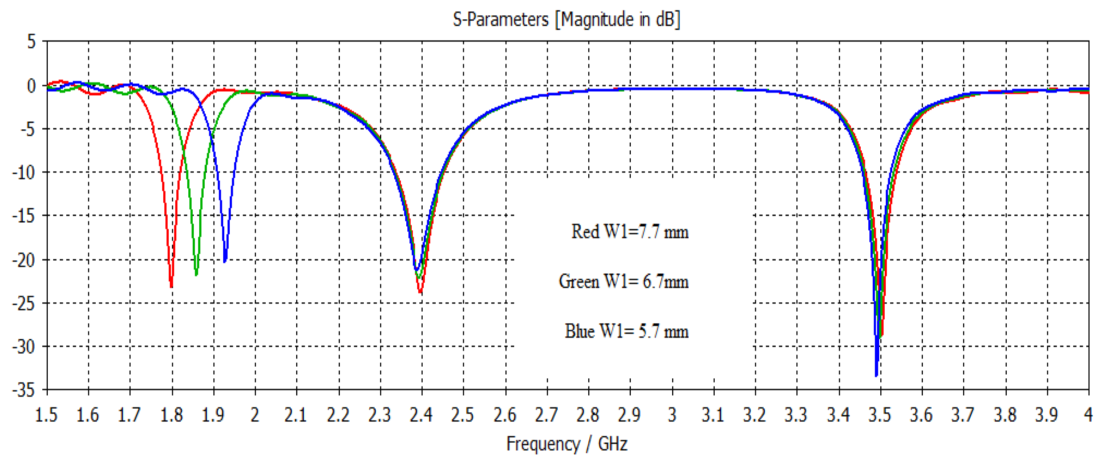


Figure5.21: Variation of the resonant frequency by decreasing W1.

Step 3: Frequency control at 2.4 GHz:

The resonant frequency at 2.4 GHz can be controlled using the length of the patch (L). Figure5.22 show the desired parameter.

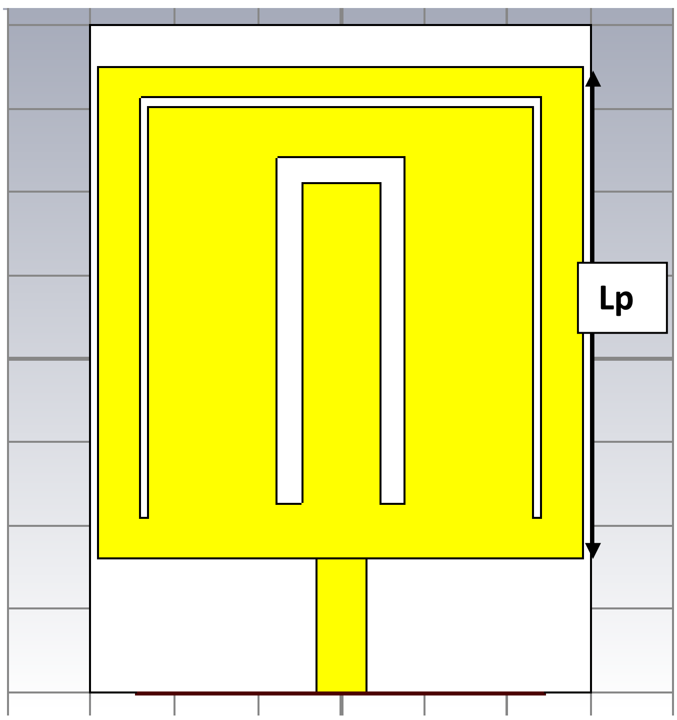


Figure 5.22: Desired Parameter Lp.

As shown in the **Figure 5.23** below, the resonant frequency at 2.4 GHz was successfully controlled using Lp. When L is varied from 29.5 mm to 28 mm, the resonant frequency at 2.4 GHz varies from 2.45 to 2.5 GHz, while the 2nd resonant remain fixe. In this case the 3nd resonant is varied little.

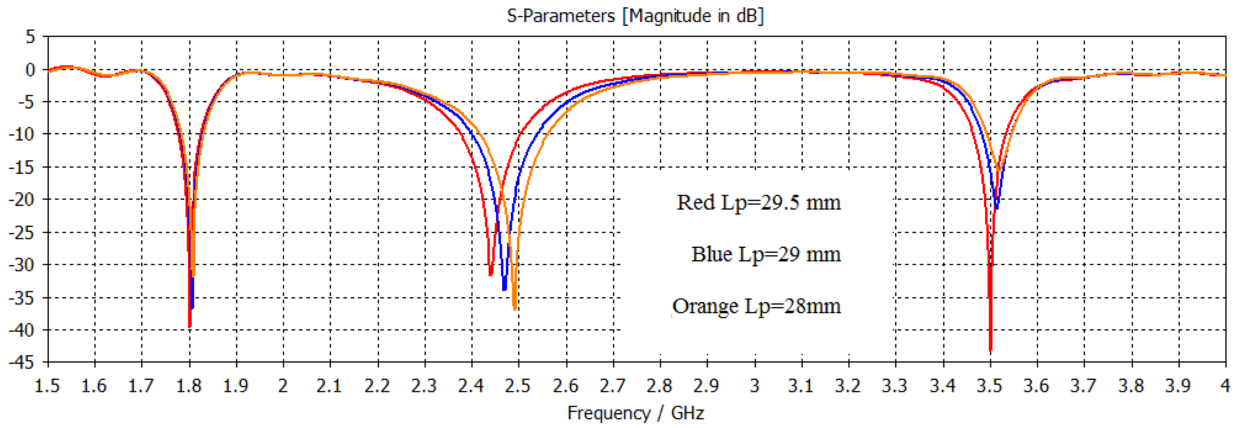


Figure 5.23: Variation of the resonant frequency by decreasingLp.

As shown in the **Figure 5.24** below, the resonant frequency at 2.4 GHz was successfully controlled using Lp. When Lp is varied from 29.5 mm to 31.5 mm, the resonant frequency at 2.4 GHz varies from 2.45 to 2.4 GHz, while the 2nd resonant remain fixe.In this case the 3nd resonant is varied little.

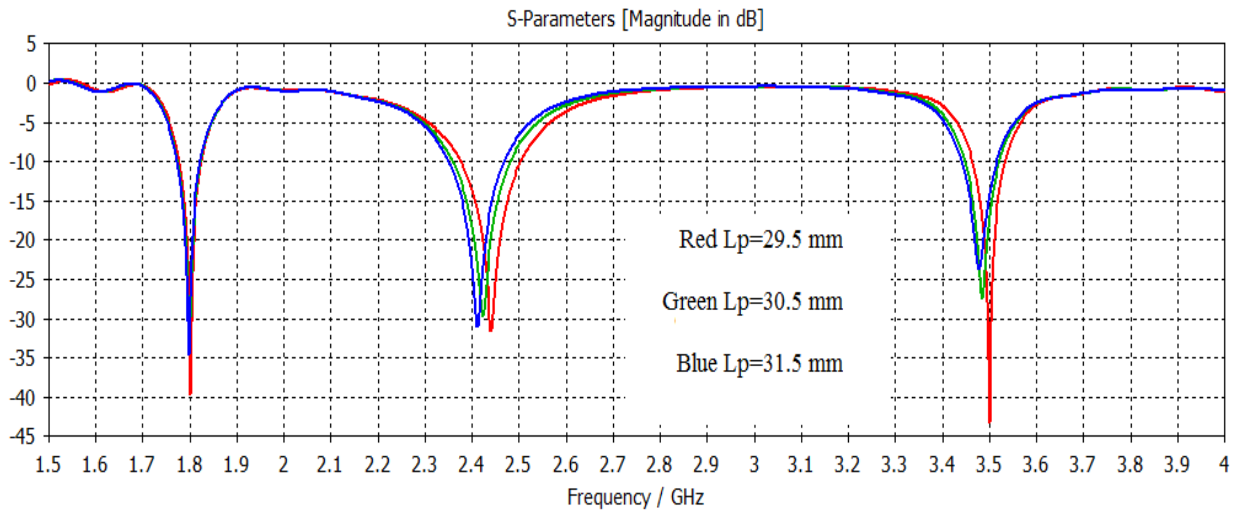


Figure 5.24: Variation of the resonant frequency by increasingLp.

5.5Simulated Results

In this section, simulation is done for the proposed triple-band U-slot microstrip patch antenna by CST Studio Suite. The proposed antenna has impedance matching better than -10 dB return loss for frequency range of 1.77-1.825 GHz, 2.37-2.5 GHz, and3.46-3.53 GHz respectively. **Figure 5.25** shows that the antenna have the maximum return loss of -39.3 dB at 1.8 GHz, -31.48 dB at 2.44 GHz, and -43 dB at 3.5 GHz. **Figure 5.26** shows the VSWR, which is mean Voltage Standing Wave Ratio and is a measure of how well matched an antenna is to the cable impedance. The value are less than 2 for the frequency range of 1.78-1.826 GHz, 2.37-3.5 GHz, and3.46-3.52 GHz respectively, which indicate that the antenna have good impedance matching. **Figure 5.27**, **Figure 5.28**, and **Figure 5.29**shows the simulated 2D radiation pattern at 1.8 GHz, 2.44 GHz, and 3.5 GHz frequency respectively.

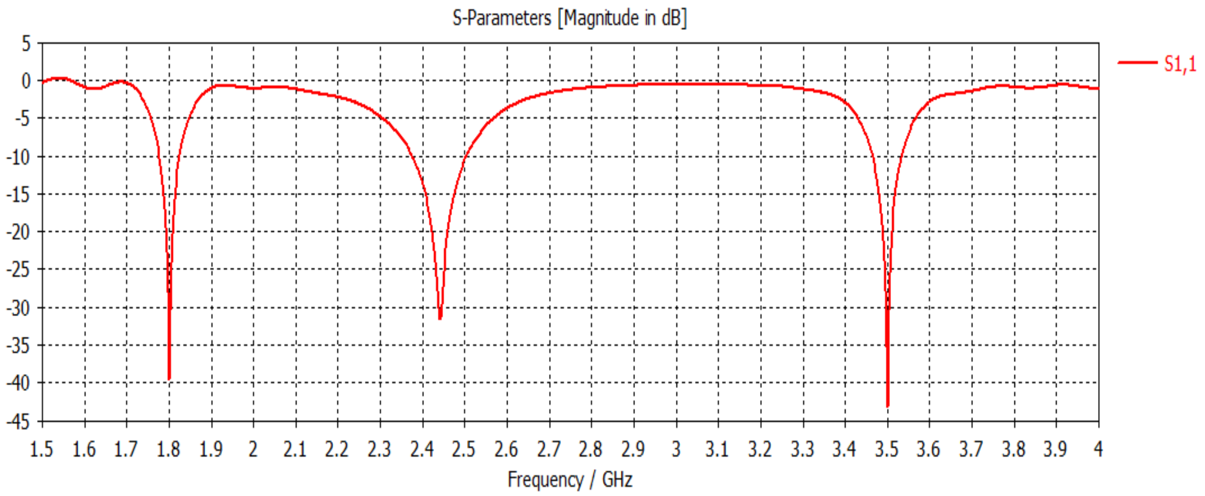


Figure 5.25: Reflection coefficient plot of the proposed antenna.

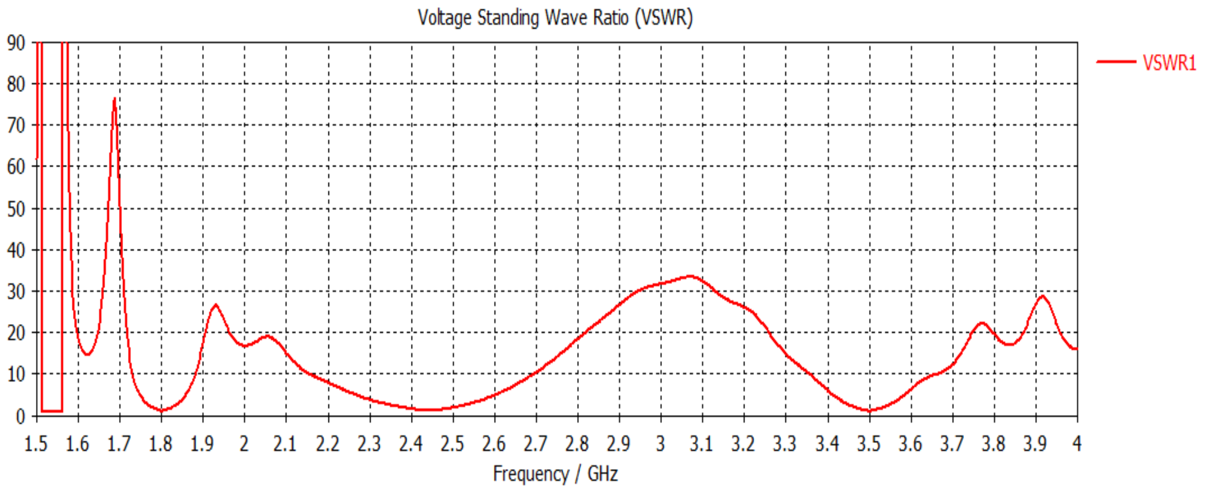


Figure 5.26:VSWR plot of the proposed antenna.

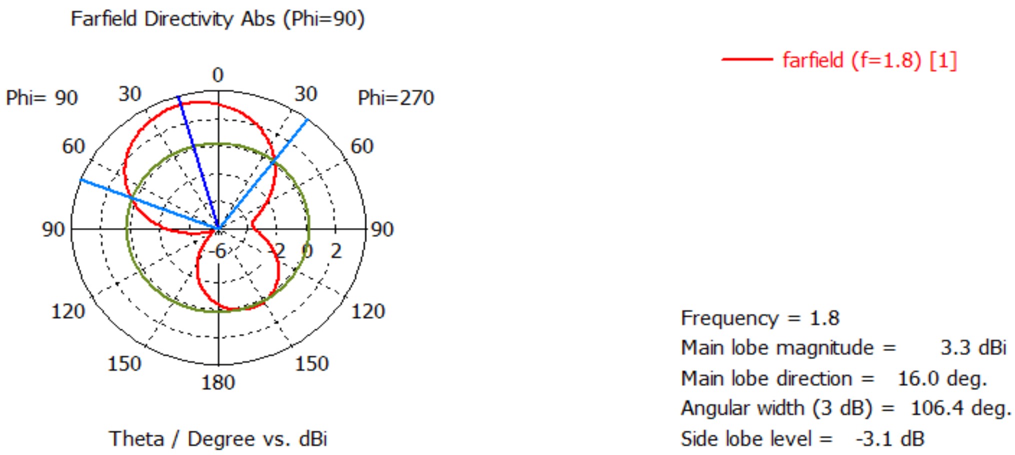


Figure 5.27: Radiation pattern of the proposed antenna at 1.8 GHz.

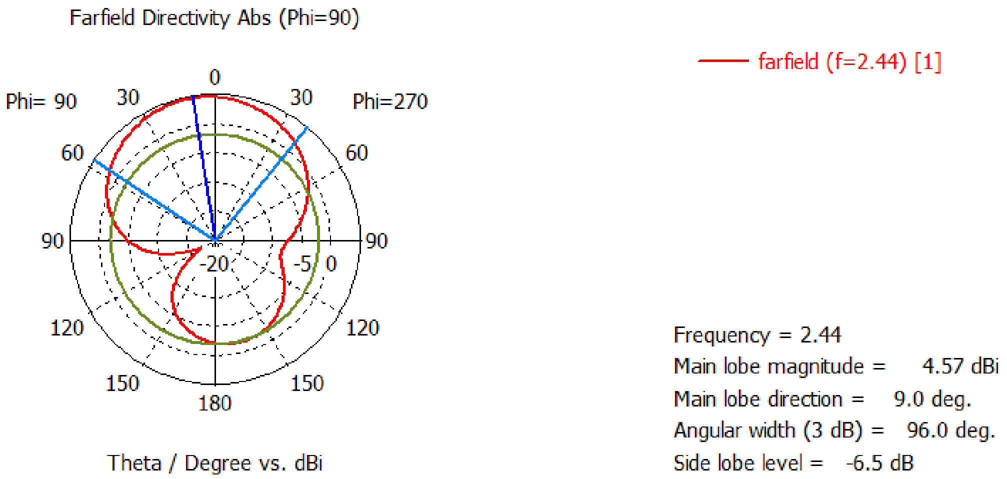


Figure 5.28: Radiation pattern of the proposed antenna at 2.44 GHz.

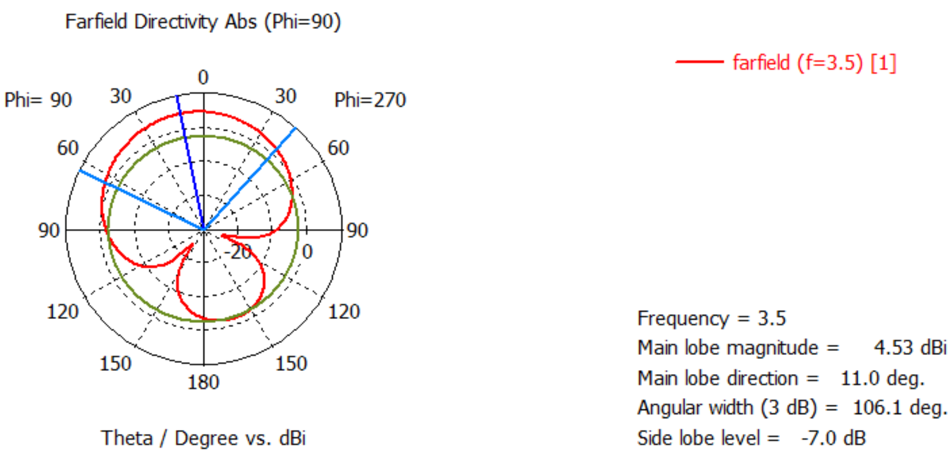


Figure 5.29: Radiation pattern of the proposed antenna at 3.5 GHz.

Figure 5.30 Shows that the proposed antenna has a good input impedance at the three resonant frequencies.

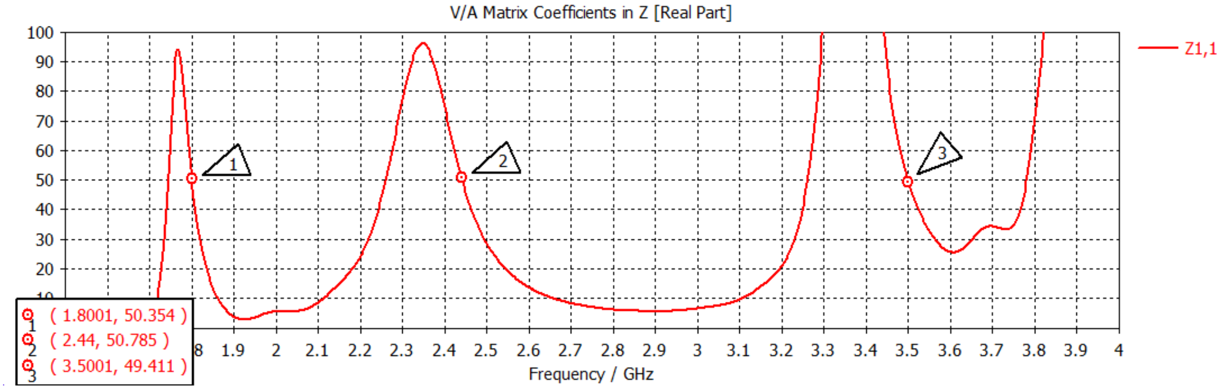


Figure5.30: Input impedance of the proposed antenna versus frequency.

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Chapter 6

Measurements and Experimental Results

Chapter 6

Measurements and Experimental Results

6.1 Introduction

In the previous chapter we presented the simulated results of our work. In this chapter we will show the experimental results of the work.

First of all, the reflection coefficient is presented with comparison between the simulated results and the experimental results. Then the experimental radiation pattern is compared with the simulated one. After that, the results of a simple experiment of the antenna in WLAN is given.

6.2 Reflection Coefficient (S11)

Figure 6.1 shows the measured S11 parameter followed by Figure 6.2 which shows the simulated S11.

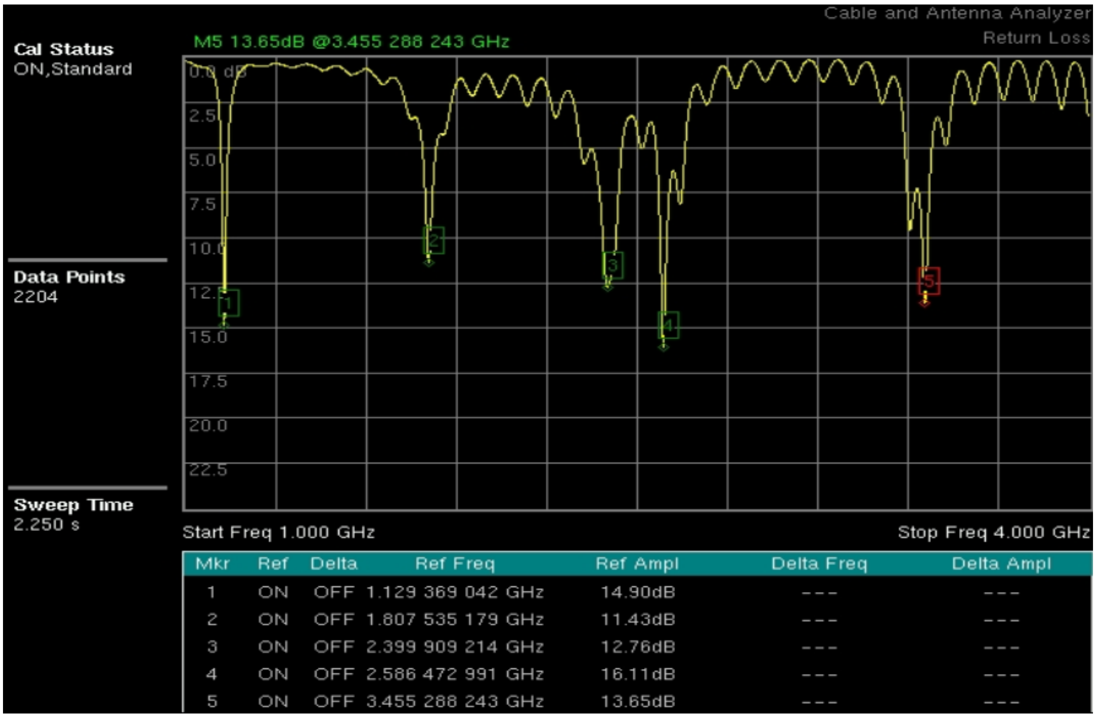


Figure 6.1: Measured Reflection Coefficient

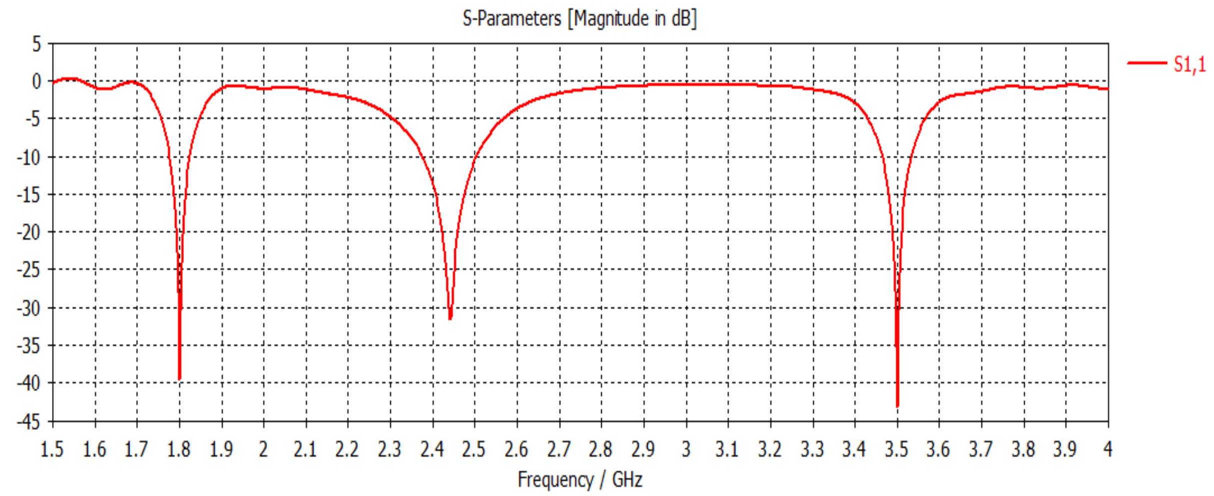


Figure 6.2: Simulated Reflection Coefficient

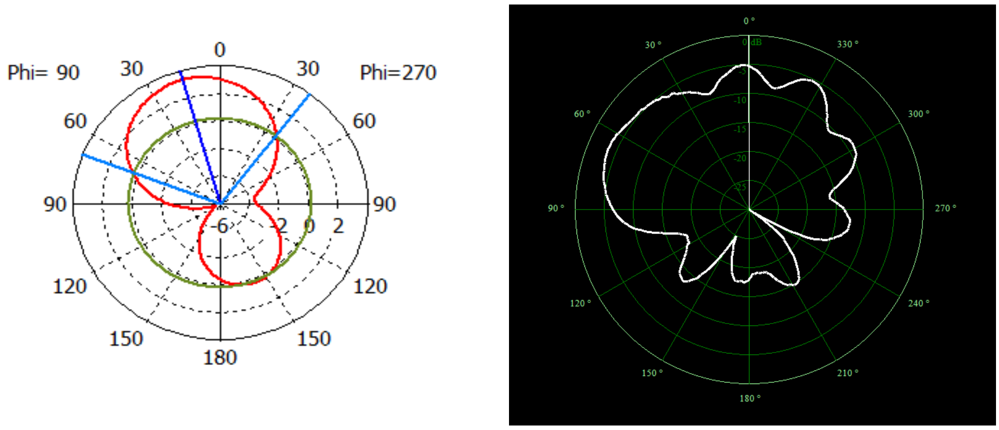
The table below present a comparison between the measured and the simulated results.

Table 6.1: comparison between the measured S11 and the simulated S11

Frequency (GHz)	Measured S11 (dB)	Simulated S11 (dB)
1.8	-11.43	-39.4
2.4	-12.76	-31.48
3.5	-13.65	-43

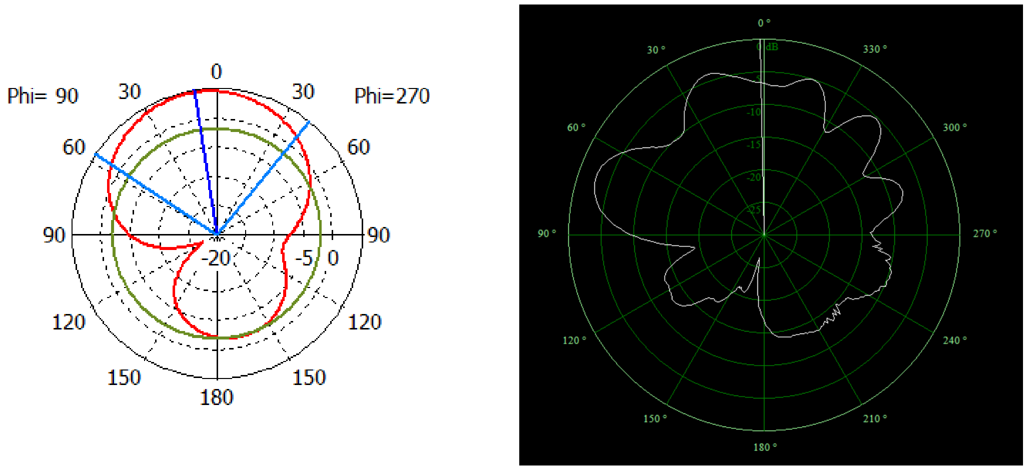
6.3 Radiation Pattern

The figures below show the simulated radiation pattern along with the measured radiation pattern for each resonant frequency.



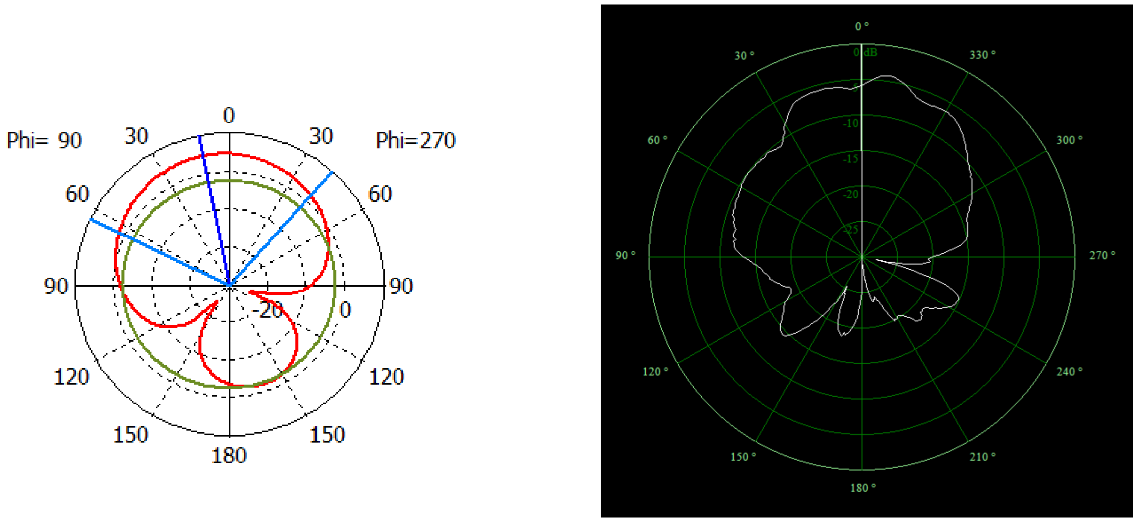
(a) (b)

Figure 6.3: a. Simulated radiation pattern at 1.8 GHz b. Measured radiation pattern at 1.8 GHz



(a) (b)

Figure 6.4: a. Simulated radiation pattern at 2.4 GHz b. Measured radiation pattern at 2.4 GHz



(a) (b)

Figure 6.5: a. Simulated radiation pattern at 3.5 GHz b. Measured radiation pattern at 3.5 GHz

6.4 WLAN Experiment

In this experiment we used the antenna in the transmitter and we measured the received power in the case of using the antenna in the transmitter and not using it in the transmitter. We got the following results using software called InsSider.

Table 6.2: Received Power Vs Distance

Distance (m)	Received Power with Microstrip (dBm)	Received Power without Microstrip (dBm)
1	-35	-40
3	-42	-45
5	-44	-54
7	-45	-59
9	-47	-61
12	-52	-63
15	-53	-65
17	-55	-67
20	-58	-70
23	-65	-71

The power versus distance curves of the router with the U-slot antenna were measured using a software called InsSider which measures real time power density. Each point measurement at each distance was averaged over many readings and repeated over several times. Figure 6.6 show the power versus distance curve.

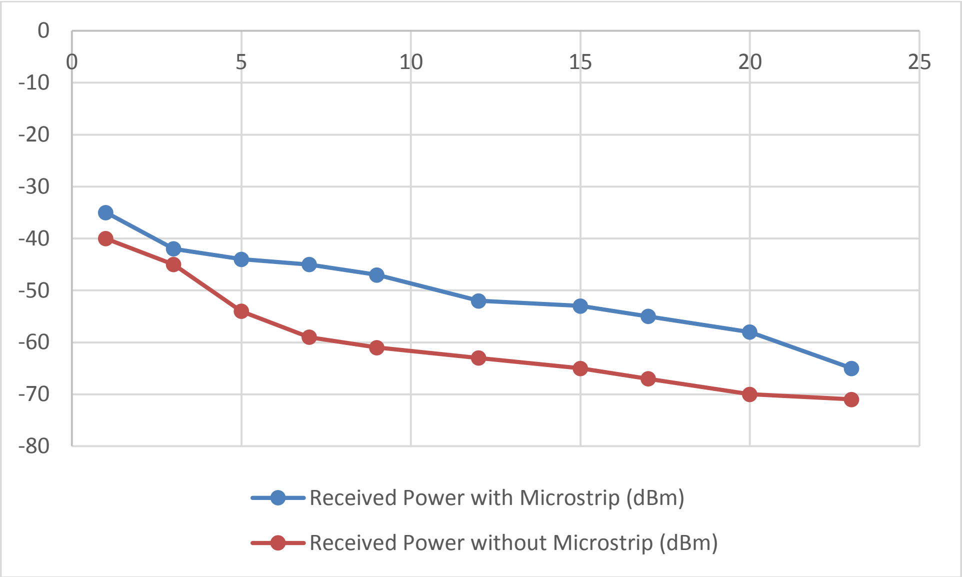


Figure 6.6: Received Power Vs Distance

Chapter 7

Conclusion and Future work

7.1 Conclusion

7.2 Recommendations for Future Work

Chapter 7

Conclusion and Future work

7.1 Conclusion

Current revolution in Telecommunication and Electronic field has a lot of challenges including design and development of a small and high efficiency antenna. Patch antenna for dual and multiband become an interesting topic these days because of its advantages such as low profile, light weight, low cost of fabrication, small size and compatibility with microwave integrated circuit (MIC) and monolithic microwave integrated circuit (MMIC).

Since current product has a small size such as personal communication service such as mobile phone and WLAN, this lead to challenge in antenna design, so modern antenna must meet the requirement of multiband. The antenna must also have a small size to be placed inside minimized wireless communication system. Microstrip patch antenna are used all around the world in several applications for government, civilian and commercial applications such as Global Positioning System(GPS), Multi-input Multi-output(MIMO), Radio Frequency Identification(RFID), WLAN and WiMAX etc.

In this project, a simple structure, low-cost, and low-profile U-slotted microstrip patch antenna has been designed to operate at three desired frequencies, that is, 1.8GHz (GSM), 2.44GHz (WLAN), 3.5GHz (WiMAX).

In the design process, the effects of several parameters on the performance of the antenna have been studied, such as, the length and the width of the patch, the lengths and the widths of the U-shaped slots, and others. Then the optimum dimensions are chosen to get the optimum performance of the antenna.

7.2 Recommendations for Future Work

The proposed antenna is designed to operate at three frequencies with reasonable bandwidth. Those frequencies are, 1.8GHz for GSM, 2.4GHz for WLAN, and 3.5GHz for WiMAX. Owing to being multi resonant antenna and its low profile and simple structure, this antenna can be used in different applications, such as, Wi-Fi networks and GSM communications.

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